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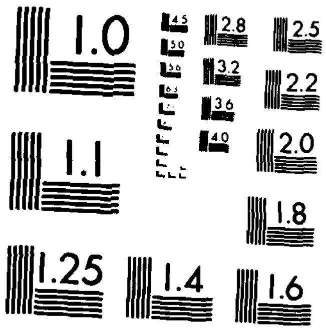

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THESIS

REAL-TIME POSITION DETERMINATIONS
USING THE GPS T14100/GEOSTAR RECEIVER

by

Peter J. Rakowsky

September 1984

Thesis Advisor: R. L. Hardy

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The NAVSTAR Global Positioning System is a worldwide, all-weather, satellite positioning system capable of high accuracy real-time position determinations The Applied Research Laboratories (ARL:UT), in conjunction with the Naval Surface Weapons Center (NSWC/DL) and other government agencies, conducted geodetic field tests of a government sponsored prototype receiver, the TI4100/GEOSTAR, in March 1984. Data were acquired from four satellites by three receivers, with antennas located at known stations, over approximately six-hour periods each day.

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Real-Time Position Determinations Using the GPS TI4100/GEOSTAR Receiver

by

Peter J. Rakowsky
Cartographer, Defense Mapping Agency
B.S., University of Maryland, 1979

Submitted in partial fulfillment of the requirements for the degree of

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September 1984

Author: Peter J. Rakowsky
Peter J. Rakowsky

Approved by: Rolland L. Hardy
Rolland L. Hardy, Thesis Advisor

Joseph von Schwind
Joseph J. von Schwind, Second Reader

Christopher N. K. Mooers
Christopher N. K. Mooers, Chairman,
Department of Oceanography

J N Dyer
John N. Dyer,
Dean of Science and Engineering

ABSTRACT

The NAVSTAR Global Positioning System is a worldwide, all-weather, satellite positioning system capable of high accuracy real-time position determinations. The Applied Research Laboratories (ARL:UT), in conjunction with the Naval Surface Weapons Center (NSWC/DL) and other government agencies, conducted geodetic field tests of a government sponsored prototype receiver, the TI4100/GEOSTAR, in March 1984. Data were acquired from four satellites by three receivers, with antennas located at known stations, over approximately six-hour periods each day.

Based on the real-time solutions acquired on March 1, 8, and 9, 1984, absolute point position determinations have an average discrepancy of 7.5 meters with a one sigma repeatability of less than a meter. Relative positions were determined to an average relative accuracy of 1:9,700 for distances of 14 to 26 kilometers.

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I. INTRODUCTION

The Naval Surface Weapons Center (NSWC), with sponsorship by the Defense Mapping Agency (DMA), has developed a system for geodetic positioning with the use of the NAVSTAR Global Positioning System (GPS) [Ref. 1]. A government sponsored prototype receiver, the TI4100/GEOSTAR, was developed by Texas Instruments through contract with Applied Research Laboratories, The University of Texas at Austin (ARL:UT) [Ref. 2]. The receiver was tested by ARL:UT in conjunction with NSWC and other government agencies over short and medium base lines in March 1984. The Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC) has expressed interest in independent analyses of the data from these tests [Ref. 3].

Absolute point positioning, as it is used in this thesis, is the determination of a position with the use of one GPS receiver. Relative positioning is the determination of two positions relative to each other with the use of two receivers. The basic premise of real-time relative positioning is that GPS observation errors are to a large extent systematic in the same general area at the same time. If such is the case, relative positioning by two receivers can locate positions relative to each other more accurately than absolute positioning alone.

Accuracy standards for horizontal control require certain relative accuracies between directly connected adjacent points. Third-order surveys are used for local horizontal control in hydrographic surveying and other local projects. Third-order, Class II standards require relative accuracies of at least 1:5,000 between directly connected adjacent points (e.g., 5 meters relative accuracy between stations separated by 25 kilometers). [Ref. 4]

Geodetic positioning with GPS has advantages over conventional surveying methods. Visibility between sites and fair weather conditions are not required. Real-time positioning has a special application in the case where the position of a station is needed in a short amount of time and before the data can be post-processed. An analysis of the real-time solutions of the GEOSTAR short and medium base line tests will give an estimate as to what degree of accuracy the system can achieve in real-time.

II. BACKGROUND

A. THE GLOBAL POSITIONING SYSTEM

The Global Positioning System is a worldwide, all-weather, satellite positioning system. GPS can be thought of as consisting of three components; the Space Segment, the Control Segment, and the User Segment. The Space Segment will consist of eighteen satellites (with three spares) in six orbit planes when fully operational in late 1988 or early 1989 [Ref. 5]. The satellites will orbit the Earth in twelve-hour periods at altitudes of approximately 20,000 kilometers. This constellation will provide four satellites in view at one time at elevations of greater than 20° above the horizon. [Ref. 6] The satellites' ground paths will be fixed. The time at which a particular satellite will be in view at a certain position will be about four minutes earlier each day due to the differences between solar and sidereal time. [Ref. 7]

The GPS satellites have on orbit weight of 950 pounds. Power is supplied by solar panels and nickel-cadmium batteries. The satellites are equipped with atomic clocks with stabilities on the order of 1 part in 10^{13}. [Ref. 8] Perturbations in the satellite orbits are caused by the forces of attraction of astronomical bodies, gravitational irregularities of the earth, and solar radiation pressure. These perturbations are compensated for by the Control Segment and frequency standard offsets. [Ref. 7]

The Control Segment consists of four monitor stations located at Alaska, Hawaii, Guam, and Vandenburg AFB; and a Master Control Station (MCS) and an Upload Station at Vandenburg AFB [Ref. 9]. The monitor stations track the

satellites then send the data to the MCS for processing to determine updated predictions of satellite and clock behavior. The updated predictions are transmitted to the satellites by the Upload Station. [Ref. 10]

B. TRANSMISSION SIGNALS

The GPS NAVSTAR satellites simultaneously transmit navigation information on 2 RF frequencies; the L1 frequency at 1575.4 MHz. and the L2 at 1227.6 MHz. Both frequencies are modulated with pseudo-random noise (PRN) codes. The Precise Positioning Service (PPS), formerly called the "P-code", is modulated on both frequencies and the Standard Positioning Service (SPS), formerly called the "C/A-code", is available only on the L1 frequency. PRN codes, different for each satellite, serve the purpose of uniquely identifying the particular satellite and provide a means of determining the signal transit time by measuring the phase shift necessary for the receiver to match codes. [Ref. 11 and 12]

The SPS is a relatively short code of 1023 bits. The code repeats itself every millisecond at a bit rate of 1.023 Mbps. Due to the short duration time of the SPS, the code is relatively easy to match and lock on to. The PPS has a 7-day code duration and 10 times the bit rate, making the PPS code relatively difficult to match with the receiver's internally generated code. The PPS offers the advantage of a finer resolution of the phase shift necessary to match codes, thus a greater measurement accuracy of signal transit time. [Ref. 11]

C. THE NAVIGATION MESSAGE

The GPS Navigation Message is modulated on both the L1 and L2 frequencies and contains information necessary to compute the user's position. The information is in the form

of a 50 bps. data stream common to both the PPS and SPS. The data frame is 1500 bits long and consists of 5 subframes of 6 seconds (300 bits) each. The Navigation Message provides information such as satellite ephemerides, system time, satellite clock behavior, and transmitter status. [Ref. 13]

Subframes are divided into ten 30-bit words. The first two words of each subframe contain system time and time synchronization information for transfer from the SPS to the PPS in the form of hand-over words (HOW) and telemetry words (TLM). The remaining 8 words contain user navigation data generated by the Control Segment. [Ref. 13]

Data Block 1 occupies words 2 through 10 in subframe one. It contains frequency standard corrections, an associated age of data word, and ionospheric delay corrections for single frequency receivers. The clock correction parameters are used to determine the satellite's clock offset from GPS time by the following equations:

$$t = t_{sv} - \Delta t_{sv} \tag{2.1}$$

$$\Delta t_{sv} = a_0 + a_1 (t - t_{oc}) + a_2 (t - t_{oc})^2 \tag{2.2}$$

where t is the GPS time in seconds measured from the beginning of the GPS week (approximately Saturday/Sunday midnight GMT), t_{sv} is the satellite's PRN code phase time at the time of message transmission, t_{oc} is Data Block 1 reference time (seconds), and a_0, a_1, and a_2 are Data Block 1 clock correction parameters (coefficients of a second order polynomial). Note that t may be approximated by t_{sv} in equation 2.2. [Ref. 13]

The age of data word (AODC) is the time between Data Block 1 reference time and the time since the last measurement used in computing the clock correction parameters

[Ref. 13]. Test data in this thesis were obtained using both the L1 and L2 frequencies, therefore, the ionospheric delay parameters for single frequency receivers contained in Data Block 1 are not used (see Van Dierendonck, et al, 1978).

Data Block 2 contains ephemeris information in subframes 2 and 3. This data includes associated age of data words (AODE) which represent the time difference between Data Block 2 reference time and the time of the last measurement used in the estimation of the ephemeris parameters. The ephemeris data includes conventional Keplerian-type parameters, secular drift terms, and harmonic coefficients used to correct for perturbations in the Keplerian orbit. [Ref. 13] The satellite's position is calculated by Van Dierendonck's algorithm [Ref. 13] with the addition of a secular drift term to correct for perturbations in the inclination of the satellite's orbit [Ref. 14].

The Message Block appears in the third through the tenth 30-bit words of subframe 4 of the Navigation Message. This space is reserved for alphanumeric messages provided to the user by the Control Segment. Space exists for 23 eight-bit ASCII characters. [Ref. 13]

Almanac information appears in Data Block 3 in the fifth subframe. Data Block 3 consists of 25 subframes allowing for almanacs of up to 24 satellites (with one dummy subframe). Twenty-five navigation messages must be received to acquire the complete data set of Data Block 3. Extra subframes can be used to repeat the almanacs for certain satellites. Satellite almanacs provide the user with less precise position and clock correction information. Almanacs aid the user in satellite selection and simplify the acquisition of signals. Almanacs include ephemeris parameters, clock correction parameters, satellite identification, and satellite health terms. [Ref. 13]

D. RECEIVER OPERATION

The GEOSTAR GPS receiver is a government sponsored version of the TI4100 commercial receiver (Fig. 2.1). The GEOSTAR is a single channel, multiplex receiver capable of tracking four satellites on the L1 and L2 PPS. The control and display unit (CDU) is a hand-held input/output device with two 16-character alphanumeric displays. The antenna assembly consists of a conical omnidirectional antenna with a preamp that allows remote operation of the receiver. Two 100-foot cables connect the antenna assembly to the receiver. One cable is used to input DC power to the preamp and output the amplified RF signals. The other cable is used for a built-in test signal injection from the receiver. [Ref. 15]

A typical GEOSTAR geodetic surveying unit consists of a 2-man team, a station wagon or van, and the GEOSTAR field set. The field set contains the receiver, CDU, the antenna assembly, a cassette tape recorder, a tripod with a leveling bracket, two 12-volt automobile batteries, an EFRATOM FRK-H rubidium oscillator, a weather station with sensors, cables, transportation cases, tools, manuals, and spare parts. The field set is easily contained and transported in the rear of the vehicle.

The antenna assembly is mounted on a standard surveyor's tripod with a leveling bracket then leveled and plumbed over the mark to be surveyed. A reference mark on the base of the antenna assembly is oriented to north using a hand compass. The height of the L2 phase center mark at the base of the antenna assembly above the survey point is measured and recorded. The antenna assembly, the power supply, the cassette recorder, the weather station, and the rubidium oscillator are then connected to the receiver with the appropriate cables. Scratch tapes are inserted in the cassette recorder for the power-up procedure.

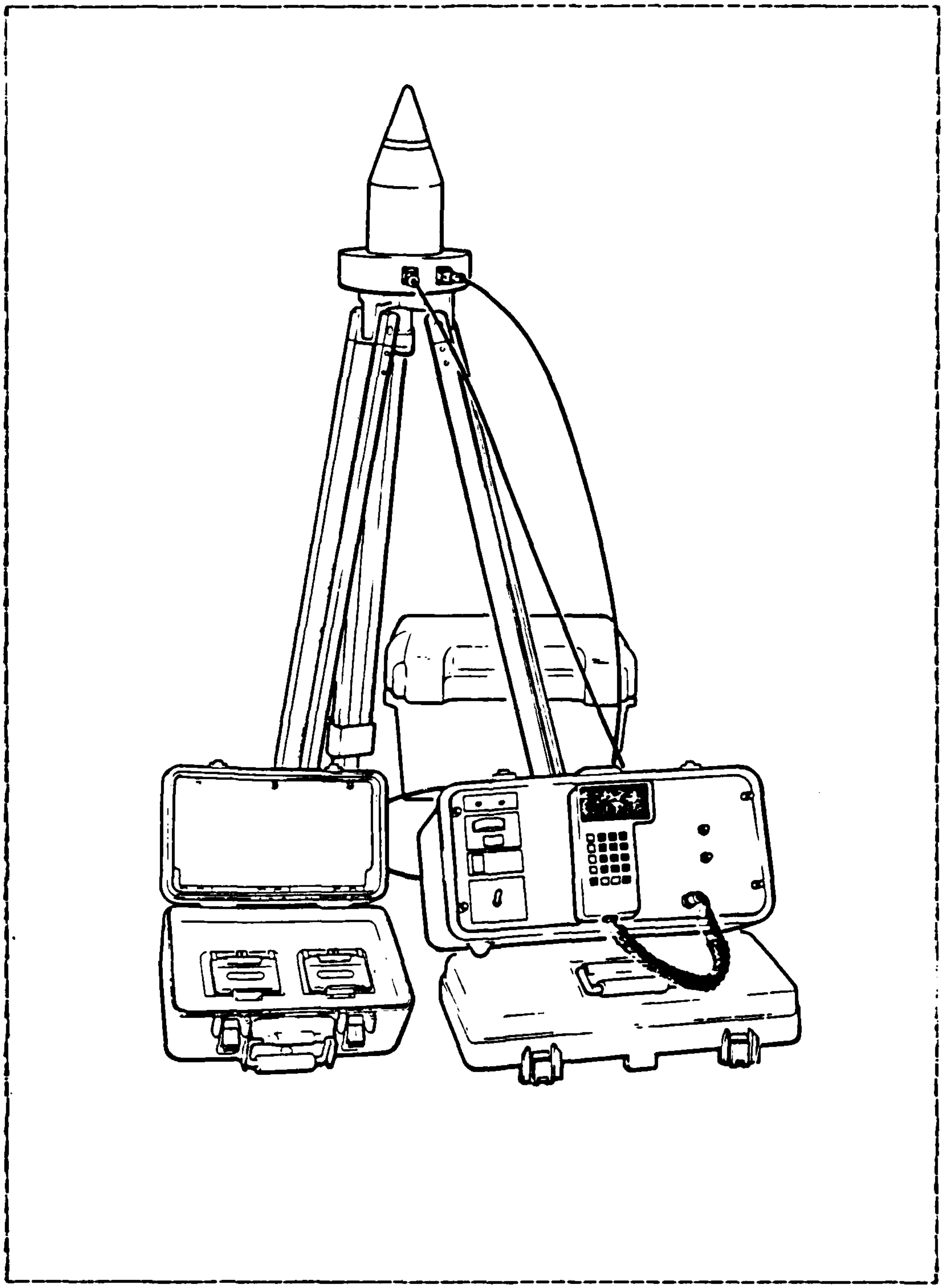

Figure 2.1 The TI4100/GEOSTAR Receiver

The system is turned on and the receiver and cassette recorder self-tests are initiated. When the self-tests are successfully completed, the GESAR bootstrap tape is inserted in Drive 1. The program is loaded and blank tapes are inserted in the two tape drives. The operator is then prompted by the CDU for input information including an estimate of the user's position, weather data, satellites to be tracked, and Doppler aiding values for each satellite. The system then operates unattended except for the replacement of cassette tapes as required and the periodic manual input of weather data (if the automatic weather station is not used).

E. POSITION COMPUTATION

The satellite's position and the time of signal transmission are computed with the broadcast ephemeris and the clock correction parameters included in the Navigation Message. The time between the transmission and the reception of the satellite signal multiplied by the speed of light is the pseudorange.

Pseudoranges used to calculate the real-time solutions are corrected for atmospheric delays in the GEOSTAR Receiver [Ref. 17]. Ionospheric refraction is nearly inversely proportional to the square of the frequency. By receiving both the L1 and the L2 frequencies, the ionospheric delay is calculated by comparison. [Ref. 16] Tropospheric delay is calculated by a model based on temperature, pressure, humidity, and the elevation of the satellite above the horizon [Ref. 17]. Knowing the positions of four satellites and the ranges to the user, the user's position is calculated by a least squares method.

F. GEODETIC DATUMS

The GEOSTAR real-time solutions are referenced in DoD World Geodetic System 1972 (WGS-72) Cartesian coordinates. WGS-72 is an earth-centered, earth-fixed, global, geodetic datum adopted by DMA in March 1974 [Ref. 18]. The reference surface is an ellipsoid that best approximates the shape of the earth's geoid. The ellipsoid is normally defined by the length of the semimajor axis and the flattening.

Latitude ranges between -90° and 90° with north positive. Longitude is measured positive east from 0° to just less than 360° from the WGS-72 reference meridian at 0".54 east of the Greenwich Meridian. The Cartesian X-axis is formed by the intersection of the reference meridian plane and the plane of the equator. The Y-axis is 90° east of the X-axis in the plane of the equator. The Z-axis is in the direction of the earth's mean rotation axis based on the average terrestrial pole of 1900-05. [Ref. 19]

The North American Datum 1927 (NAD-27) is a regional datum based on the Clarke 1866 Ellipsoid with the origin at Meades' Ranch, Kansas. The Clarke 1866 Ellipsoid minimizes the deflection of the vertical and geoidal undulations in the continental United States. The National Ocean Survey (NOS), the National Geodetic Survey (NGS), and the United States Geological Survey (USGS) use NAD-27 coordinates in most survey operations. The transformation from NAD-27 to WGS-72 reference systems creates offsets of the order of 5 meters [Ref. 2]. It is assumed that this error is removed when the reverse transformation is made; but the error source will still exist in the analysis of the WGS-72 point position discrepancies.

III. ANALYSIS METHODS

A. EXPERIMENT DESIGN

Relative position field testing of the GEOSTAR Receiver was performed in central Texas in February and March 1984. Three receivers, each with an antenna located over a different known position, were operated continuously over approximately the same period of satellite visibility. Four satellites, with PRN codes 6, 8, 9, and 11, were tracked in these tests. The period of data gathering was coordinated with the time period in which all four satellites were in view at the same time. The real-time positions of the antennas were recorded every 12 seconds over approximately a six-hour period each day. The data were recorded on cassette tape then transferred to 9-track tape by ARL:UT.

B. GPS USER TAPES

The recorded data and the associated position coordinates used in the analysis were obtained from NSWC/DL. The GPS User Tapes are a standardized format, 9-track magnetic tape. The tapes are unlabelled, ASCII coded, 1600 bpi, with 80 characters per physical record and 1 record per block.

The first file on the tapes consists of header comment records. This file assists the user in identifying the tape and includes information such as the date and site of the data acquisition.

Data files begin with an 80-character control record (Data Item List) which identifies the types of data that follow. The first location of all records is reserved for a control character. The Data Item List control record has an asterisk '*' in the first position followed by an integer in

the next three positions which specifies the number of times to repeat the sequence of the Data Item List. The remaining 76 characters contain up to 19, 4-digit data type identifiers which specify the type of data that is to follow the control record. Control records are read with a (A1,I3,19I4) format.

Data information are one or more records in length and divided into groupings called data items (Tab. I) [Ref. 19].

TABLE I

Data Types of GPS User Tapes

Item Identifier	Data Type
0001-0999	Exchange conversion program information
1000-1999	Constant equipment related data
2000-2999	Campaign identifying data
3000-3999	Infrequent measurement data
4000-4999	Space vehicle related data
5000-5999	Weather data
6000-6999	Real-time solution data
7000-7999	Measurement data
8000-8999	Post analysis data

The data type identifiers of the Data Item List specify the order and the format of how the data is to be read.

Data used in the analysis were read from the user exchange tapes using a slight modification of the sample input program contained in reference 19 (App. A). Real-time solution information (data type 6010) was read from the tapes and written to mass storage and retained. Other information such as measurement data types (data type 920), real-time solution configuration (data type 1150), and

antenna location (data type 2210) were read manually from the first page of the printouts of the tapes.

C. COORDINATE TRANSFORMATIONS

The coordinates of the stations used in the field testing were given in NAD-27 geodetic coordinates. The real-time solution output of the GEOSTAR Receiver are in WGS-72 Cartesian coordinates. To make comparisons of the given positions to the observed positions, the given positions were transformed to WGS-72 Cartesian coordinates. The transformation was done using the Abridged Molondensky formulas contained in the NGS's conversion program (D035-41) for the HP-41CV programmable calculator. The program prompts the user for the values of the origin shift between coordinate systems. The X, Y, and Z origin shifts for transforming from NAD-27 to WGS-72 are -22, 157, and 176 meters, respectively [Ref. 20]. These values differ from the origin shift values supplied with the transformation program by NGS. The NGS values are -12.547, 155.804, and 175.369, for the X, Y, and Z origin shifts, respectively. The program generates semimajor axis and inverse flattening parameters of both reference systems (Tab. II).

TABLE II
Transformation Program Parameters

Ellipsoid	a (meters)	1/f
Clarke 1866	6,378,206.4	294.9786982
WGS 72	6,378,135.0	298.2600000

D. SATELLITE UPDATES

The ephemeris elements and clock model updates occurred at identical times according to the data recorded in field tests. An approximation of the update times is calculated by subtracting the Age of Data (AODE) from the ephemeris reference time (t_{oe}), i.e.,

$$\text{update time} = t_{oe} - \text{AODE} \tag{3.1}$$

The update times changed by -496, 1052, or 1552 seconds when the computation of equation 3.1 was performed for each satellite with subsequent occurrences of the broadcast ephemeris on the recording. The change is due to packing of bits in the transmissions of the AODE values. An approximation of the update times is made, within a few minutes, by using the first AODE values that change to smaller numbers (on the order of 1 to 2 hours) from previously recorded large values (on the order of 24 hours). [Ref. 14]

E. AVERAGING METHODS

Relative position determinations were made using real-time solutions from two different stations at the same GPS time tags. Computer programs were written to read the real-time solutions from mass storage and compute the discrepancies between the observed and the given WGS-72 coordinates of pairs of stations at common GPS times. The beginning and ending times of data acquisition varied among the three receivers operated during the same time period; thus, the effect of comparing solutions at the same time tags resulted in the elimination of some of the real-time solutions from the analysis. In effect, the tape with the earlier starting time was spooled forward to correspond to the starting time of the first real-time solution recorded by the receiver

that began operation at a slightly later time. Similarly, the time of the last solution common to both receivers is the last solution recorded by the receiver that ended operation first.

A mean position was determined in two different ways to show the effect of the ephemeris and clock updates on the real-time solutions and to eliminate real-time solutions with large discrepancies from the averaging. In general, relatively large discrepancies are evident in roughly the first hour of receiver operation. The real-time solution discrepancies of pairs of stations were averaged beginning with the values one hour after and two hours after the first solution time common to both receivers. In these tests, beginning the averaging one hour after the initial solutions corresponds to averaging the solutions that were recorded a short time before or after the update times and through the remainder of the recording session. Beginning the averaging two hours after the initial solutions corresponds to using only those values that were recorded much after the updates and through the remainder of the session. Real-time solutions are treated as independent observations in the statistical analysis.

F. COMPUTATIONS

The distances between stations (d), in the WGS-72 reference system, are computed by equation 3.2 where X_1, Y_1, and Z_1 are the WGS-72 Cartesian coordinates of one of the stations, and X_2, Y_2, and Z_2 are the coordinates of the other station of the side. The side-lengths are calculated

$$d = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2 + (Z_1 - Z_2)^2} \qquad (3.2)$$

for both the given coordinates and the mean values of the GEOSTAR real-time solution coordinates. The discrepancies between the two are computed by subtracting the given distances from the observed distances. Discrepancies are used in the averaging to save computer time and to reduce round-off error.

The absolute value of the point position discrepancies are computed by equation 3.3 where the subscripts o and g represent the observed and given values, respectively.

$$\delta = \sqrt{(X_o - X_g)^2 + (Y_o - Y_g)^2 + (Z_o - Z_g)^2} \qquad (3.3)$$

The standard error of a single observation was calculated as a measure of the precision of the real-time solutions. The means and standard errors of a single, 12-second real-time solution were calculated for the coordinate discrepancies and the point position discrepancies. Comparisons are made for the two averaging methods (Sect. III E). The mean WGS-72 Cartesian coordinate discrepancies were used to compute the final observed positions. The observed positions are computed by subtracting the discrepancies from the given coordinates.

G. GEODETIC COMPARISONS

Geodetic accuracy standards for horizontal control require certain relative accuracies between directly connected adjacent points. The distances between points are computed along the ellipsoid - the geodesic. To compare the accuracies of the observed positions with the standards for geodetic control, the WGS-72 Cartesian coordinates of the observed positions are transformed to NAD-27 geodetic coordinates. The transformations were done using a modification of NGS's D035 program for the HP-41CV programmable

calculator. The modified version uses the same parameters as those contained in the original program (Tab. II).

The geodetic inverse computation is used to calculate the geodetic distance and azimuths between two known points. The inverses between given positions and between observed positions were computed and compared.

To simulate the positioning of an unknown station, one station of a side is held fixed and the other station is located using the direct computation. The coordinates of the known position and the distance and azimuth to the unknown position are the input variables and the coordinates of the unknown station are computed. The distance and azimuth calculated by the inverse computation of the observed point positions are used in this calculation. The direct and inverse computations were done on the IBM 3033 based on Puissant's Coast and Geodetic Survey Formula [Ref. 21].

The standard errors of the discrepancies of the geodetic position determinations for entire recording sessions are calculated as an approximation of the repeatability. To do so, the two point position discrepancies of each station on days 61 and 68 must first be averaged to determine a single value for the station.

IV. RESULTS AND DISCUSSION

A. GIVEN POSITIONS AND DISTANCES

Data in this report are from relative position tests of March 1, 8, and 9, 1984. Three receivers were operated simultaneously over a period of approximately six hours. The antennas of the March 1st tests were located over a second-order position and two of its reference marks. The triangle has side-lengths of approximately 30 meters. The tests of March 8th and 9th were conducted at first-order survey points separated by distances of 14 to 25 kilometers. The data of the tests at one of the positions on March 9th was not available at the time of this writing. The data gathered on March 1st will be defined as the short base line tests and the 14 to 25 kilometer testing will be termed medium base line tests. Tables III and IV give the names and the NAD-27 coordinates of the stations and Table V gives the distances and azimuths in each triangle. Distances and azimuths were calculated using the inverse computation (Sect. III G).

The NAD-27 coordinates of the given positions were transformed to WGS-72 Cartesian coordinates using a NGS transformation program (D035-41). The ellipsoidal heights are corrected for the heights of the antennas above the station marks prior to the transformations. The heights of the antennas above the stations (data type 2110) were read manually from the first page of the printouts of the tapes. The distances between the points in WGS-72 Cartesian coordinates were calculated using equation 3.2 (Tab. VI).

The computed side distances for the WGS-72 Cartesian coordinate system are in all cases greater than or equal to

the computed geodetic distances. In the medium base line tests, the differences were found to increase by .0035

TABLE III

Station Names

J.D.	Number	Name	Abbreviation
61	85019	ARL 10563 DMA	JMR
	85020	ARL 10563 RM 1 DMA	RM1
	85021	ARL 10563 RM 2 DMA	RM2
68,69	85022	BR ZERO	BZERO
	85027	PILOT KNOB 1935	PILOT
	* 85028	BALD KNOB 1935	BNOB

* Station not used in March 9th analysis

TABLE IV

NAD-27 Station Coordinates

Station	North Latitude	West Longitude	Ht. (m.)
JMR	30° 22' 56".74285	97° 43' 35".97558	235.5
RM1	30° 22' 57".54452	97° 43' 36".31041	235.7
RM2	30° 22' 57".06234	97° 43' 35".01009	235.6
BZERO	30° 23' 16".31238	97° 43' 42".05790	238.4
PILOT	30° 09' 30".93387	97° 42' 28".08922	215.9
BNOB	30° 20' 07".61000	97° 35' 30".84700	204.4

percent of the length of the line. Differences of .911, .748, and .534 meters were computed for the side-lengths of approximately 25.5, 22.6, and 14.3 kilometers, respectively. These differences occur because the Cartesian distances are computed between each point; the geodetic distances are computed from the projections of the points on the ellipsoid

which does not account for the ellipsoidal heights. The distances between BZERO and PILOT are equal to the nearest

TABLE V

NAD-27 Geodetic Distances and Azimuths

Side	Distance (m.)	Azimuth
JMR - RM1	26.255	340° 05' 34".72573
JMR - RM2	27.591	69° 06' 37".54898
RM1 - RM2	37.759	113° 09' 19".14446
BZERO - PILOT	25,492.277	175° 32' 48".25379
BZERO - BNOB	14,346.955	113° 51' 26".80840
BNOB - PILOT	22,556.303	209° 40' 09".53915

TABLE VI

WGS-72 Side-length Distances

J.D.	Side	Distance (m.)
61	JMR - RM1	26.255
	JMR - RM2	27.593
	RM1 - RM2	37.759
68	BZERO - PILOT	25,493.188
	BZERO - BNOB	14,347.489
	BNOB - PILOT	22,557.051
69	BZERO - PILOT	25,493.188

millimeter for tests run on days 68 and 69 even though the heights of the antennas above the stations were different on both days.

B. SATELLITE UPDATE TIMES

The ephemeris and clock update times occurred approximately one hour after the start of data acquisition in these tests. There are approximately 25 to 30 recordings of the broadcast ephemeris (data type 4110) during the six-hour recording periods. The update times were computed (eqn. 3.1) using the AODE values that changed from large numbers to much smaller numbers in subsequent recordings of the broadcast ephemeris (Tab. VII). Satellites with PRN codes 9 and 11 were updated approximately one-half hour after the updates of codes 6 and 8 on days 61 and 69. According to the recorded data, all four satellites were updated at approximately the same time on day 68.

TABLE VII

Satellite Update Times (Seconds)

J.D.	PRN codes	t_{oe}	AODE	t_{oe} - AODE
61	6,8	378,000	6,144	371,856
	9,11	378,000	4,096	373,904
68	6,8,9,11	378,000	6,144	371,856
69	6,8	460,800	4,096	456,704
	9,11	464,400	6,144	458,256

C. BEHAVIOR OF THE REAL-TIME SOLUTIONS

1. WGS-72 Coordinate Discrepancies

The real-time solutions were read from the GPS User Tapes and retained. The solutions of pairs of stations, with time tags of real-time solutions common to both, were

used in the analysis. The discrepancies between the observed coordinates and the given WGS-72 coordinates (observed - given) were computed and plotted over time (Figs. 4.1 - 4.8). The vertical arrows in the figures indicate the times of satellite updates (Tab. VII). The tick marks on the horizontal (time) axis represent one hour.

In general, the X, Y, and Z coordinate discrepancies begin with large values in the initial solutions and then become smaller and more consistent after satellite updates and over time. There is a significant improvement in the discrepancies of the observed coordinates near the time of the update of PRN codes 6 and 8 at station JMR and near the update of codes 9 and 11 at station RM1 on day 61 (Figs. 4.1 and 4.2). The precision of the discrepancies in each coordinate increase at all three stations on day 61, a short time after the update of codes 9 and 11. The discrepancies at stations BZERO and PILOT on day 68 decrease approximately one hour after the initial solutions (Figs. 4.4 and 4.5).

2. WGS-72 Point Position Discrepancies

The absolute values of the point position discrepancies of pairs of stations with common time tags were computed (eqn. 3.3) for five-minute time segments and plotted with the standard errors over time (Figs. 4.9 - 4.16). In general, the point position discrepancies and the standard errors decrease after satellite updates and over time. Except for the general trend, there is no obvious correlation of the accuracies (discrepancies) and the precision of the five-minute time segments at all stations on the same day.

3. WGS-72 Side-length Discrepancies

Relatively high accuracy side-length determinations are evident at certain times; however, the times of these

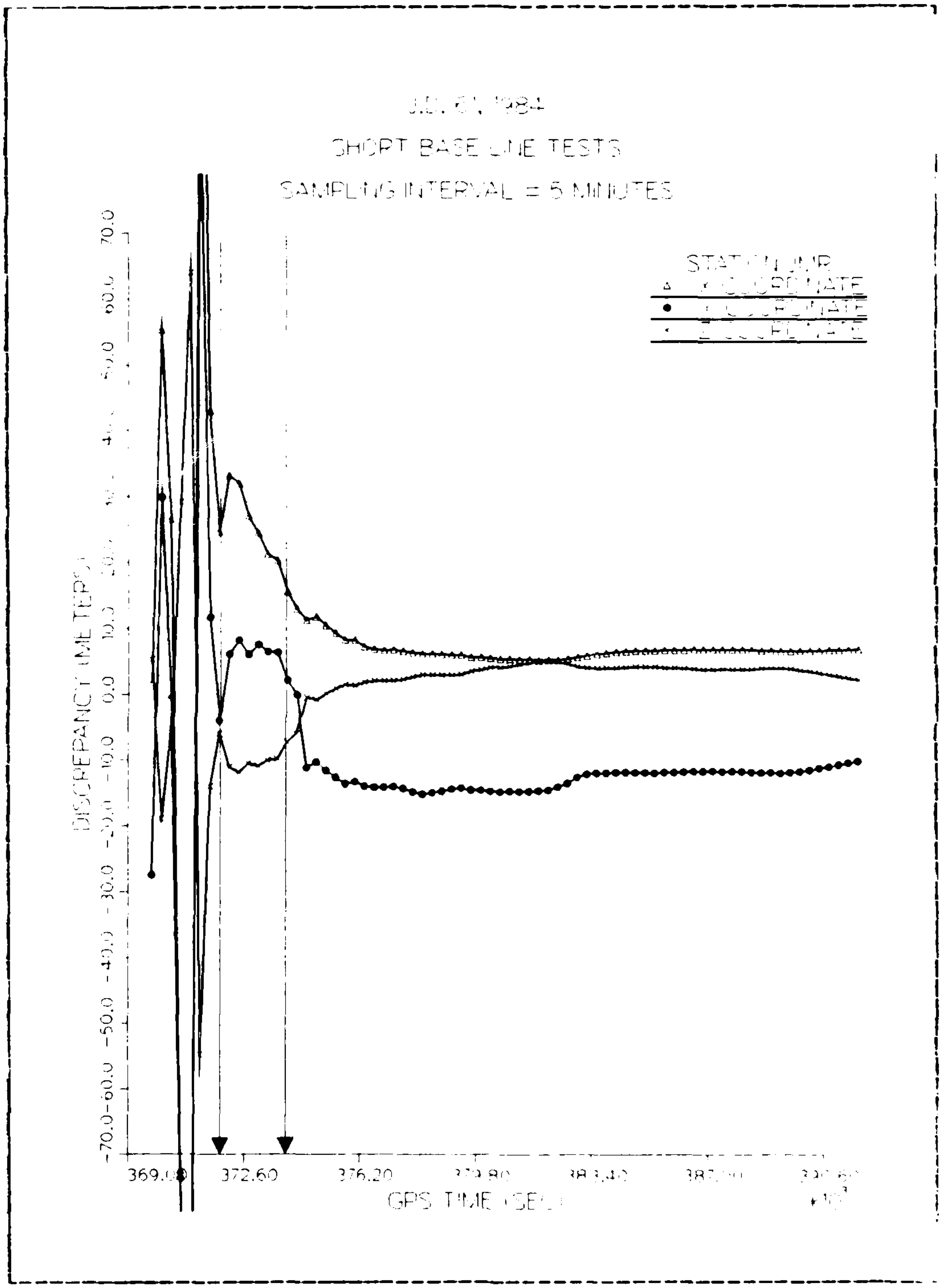

Figure 4.1 WGS-72 Coordinate Discrepancies

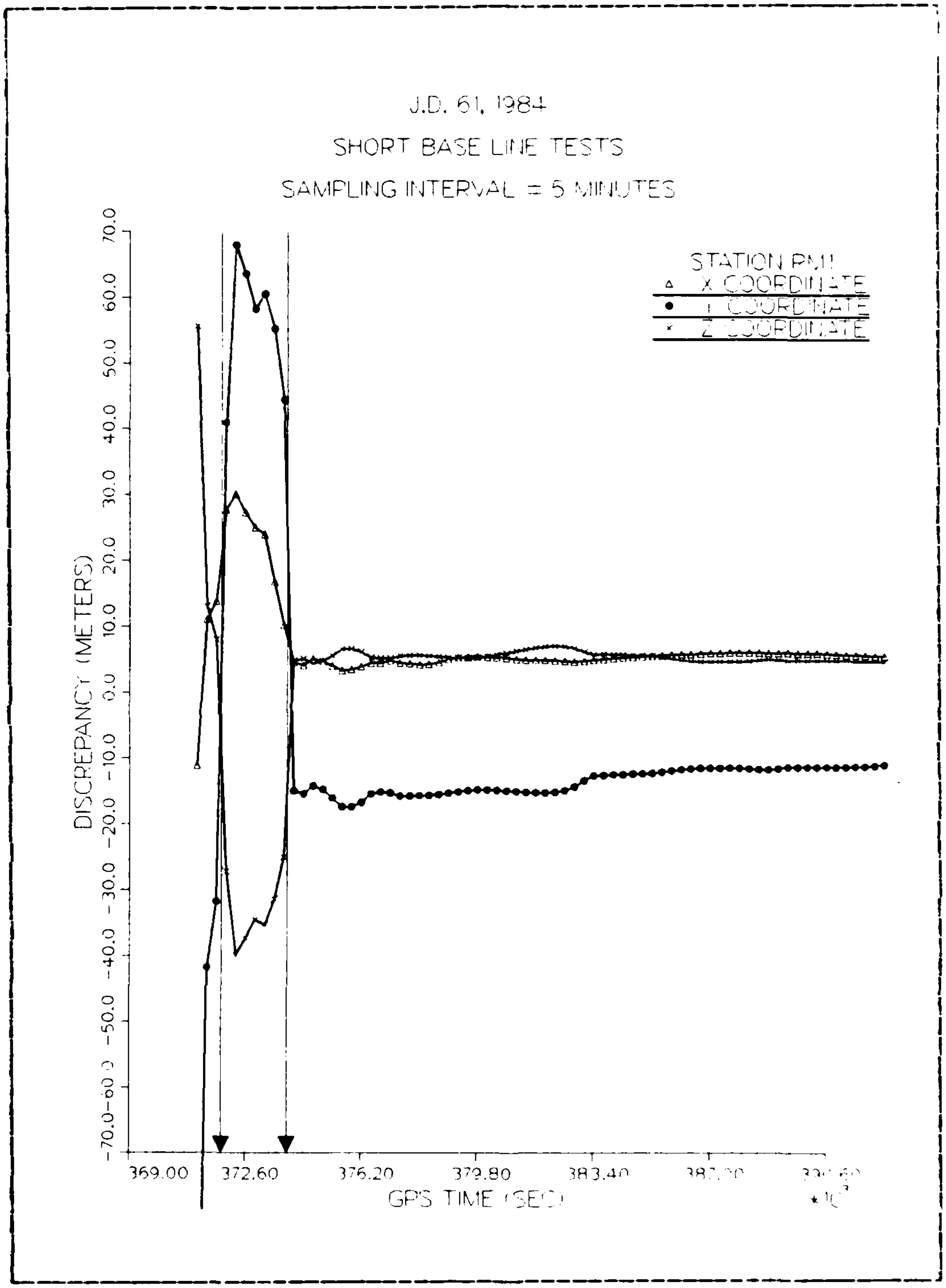

Figure 4.2 WGS-72 Coordinate Discrepancies

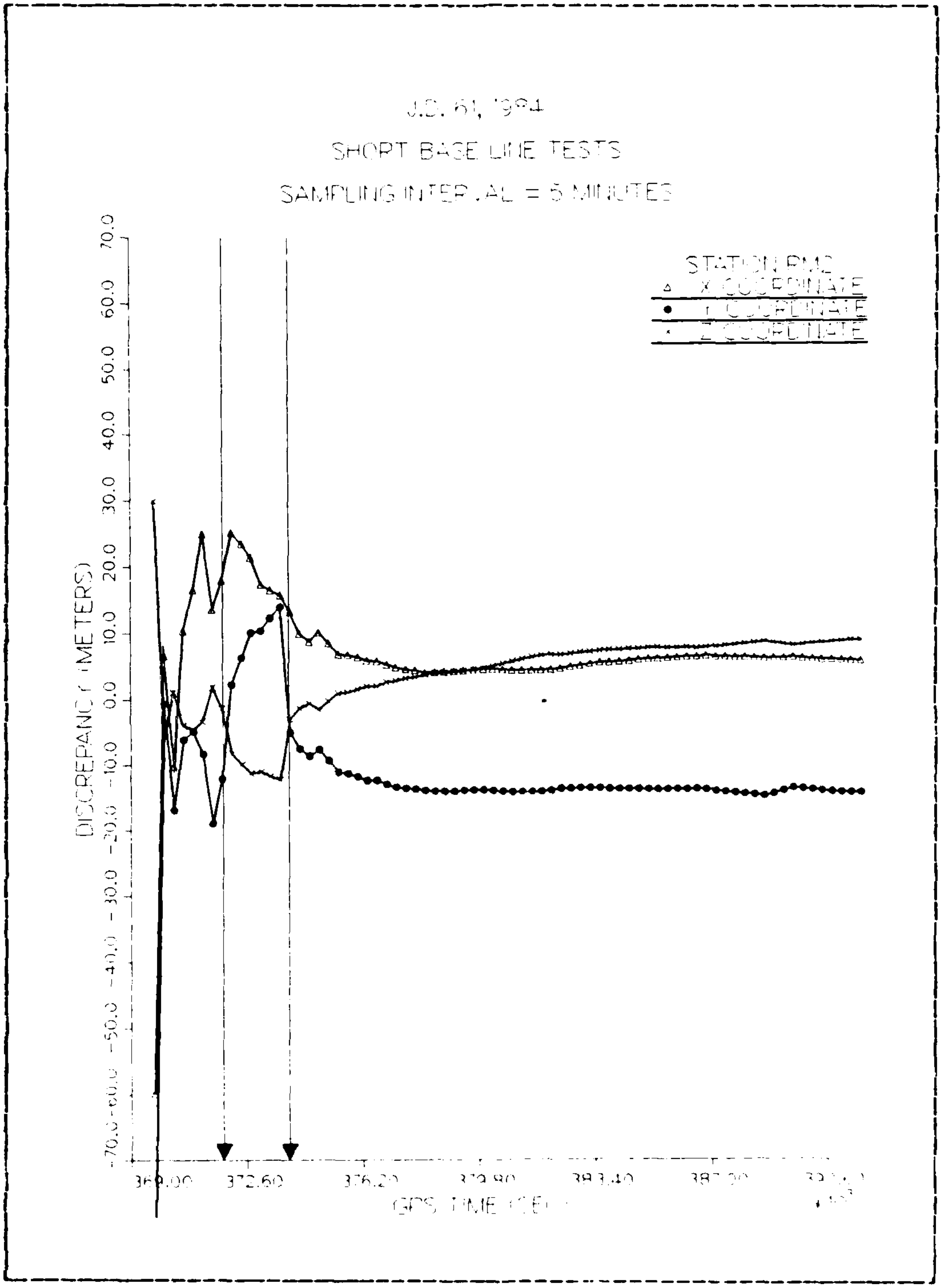

Figure 4.3 WGS-72 Coordinate Discrepancies

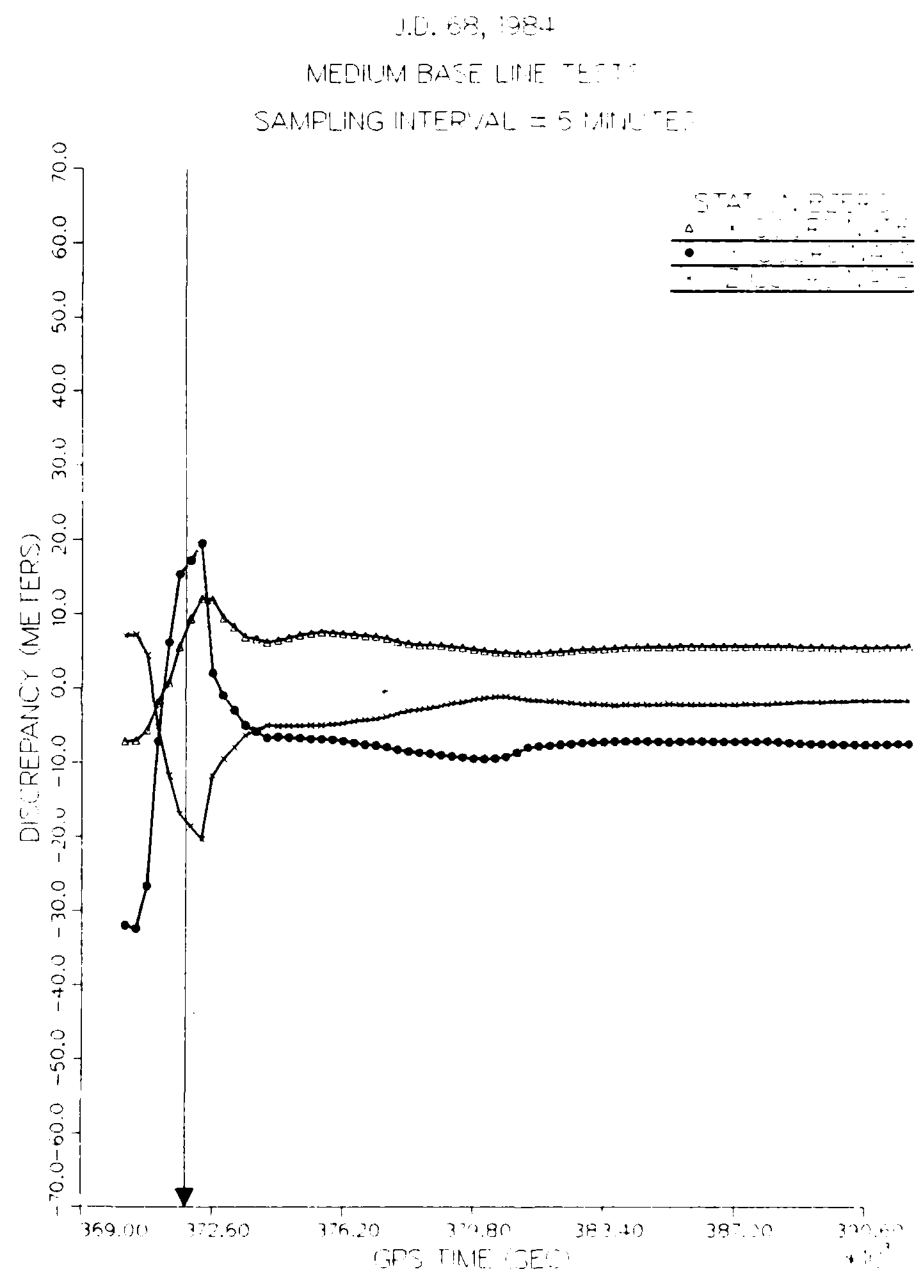

Figure 4.4 WGS-72 Coordinate Discrepancies

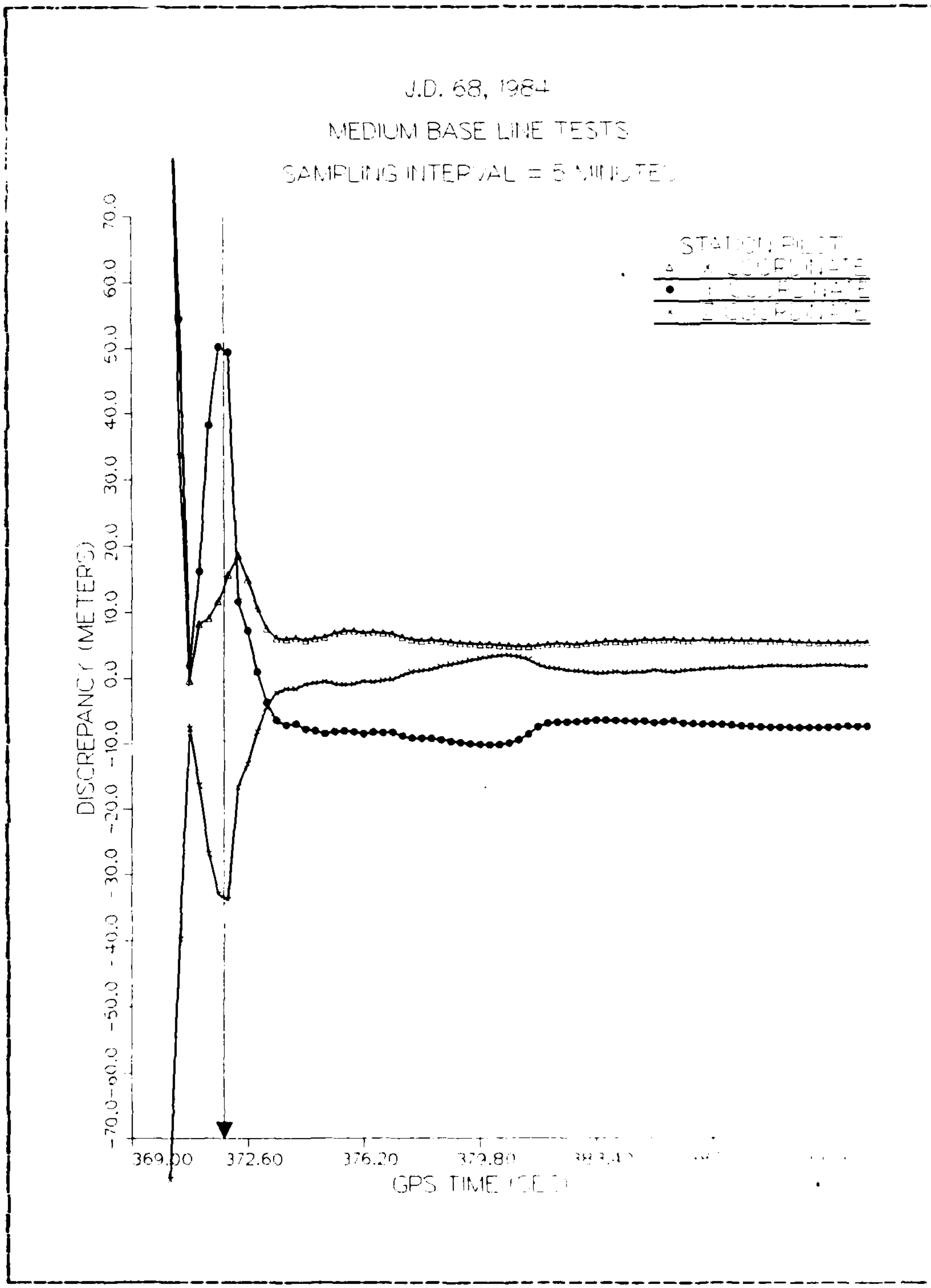

Figure 4.5 WGS-72 Coordinate Discrepancies

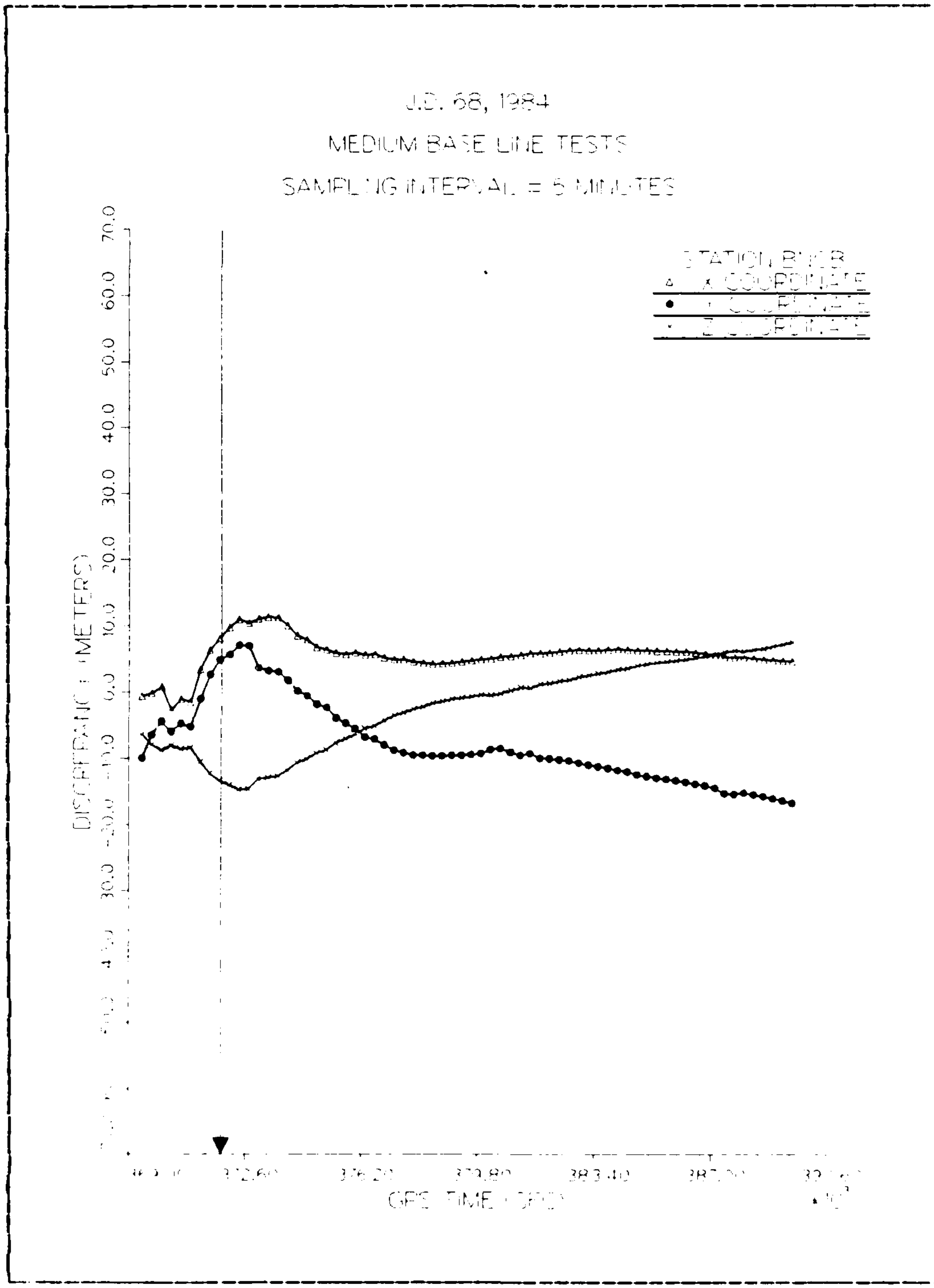

Figure 4.6 WGS-72 Coordinate Discrepancies

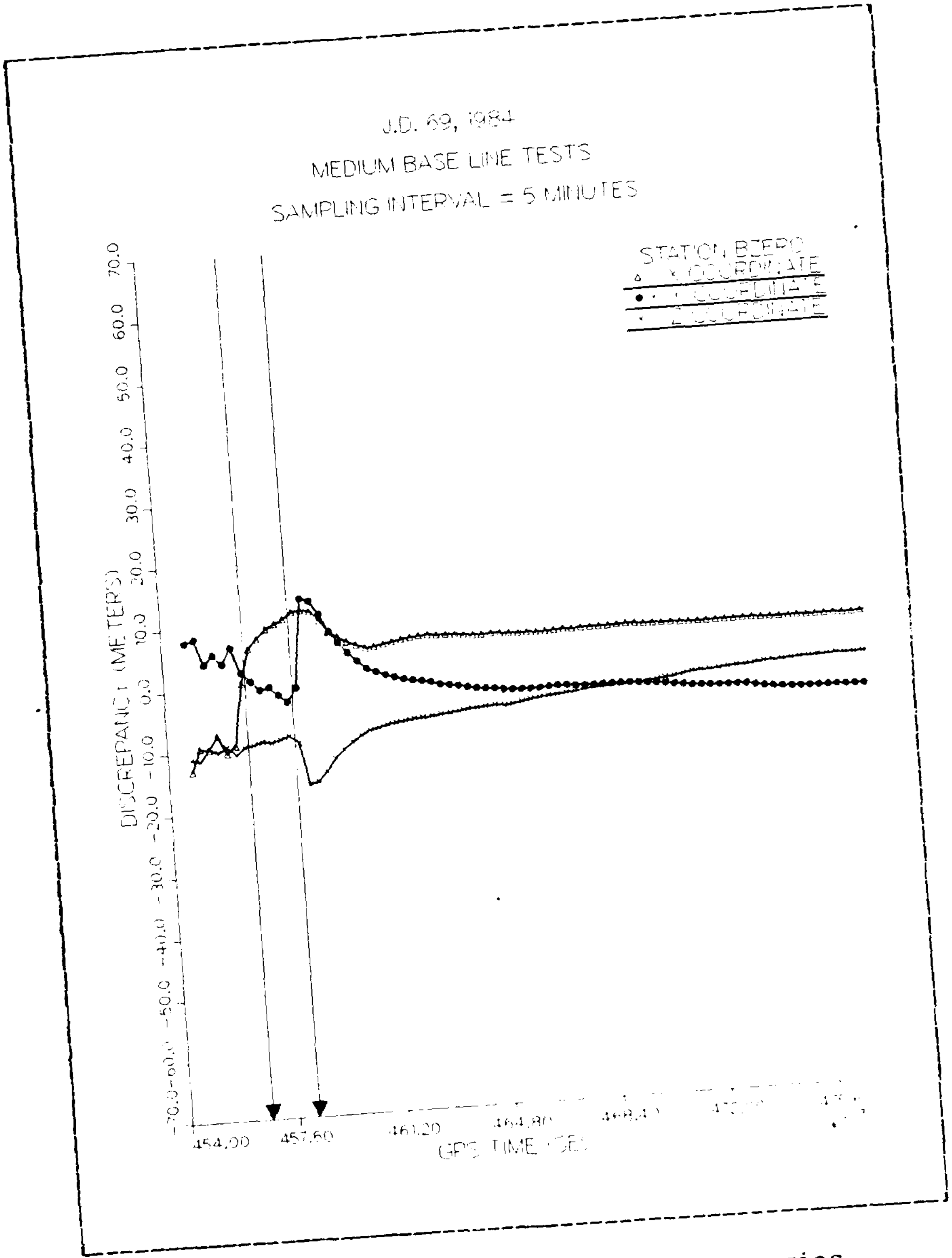

Figure 4.7 WGS-72 Coordinate Discrepancies

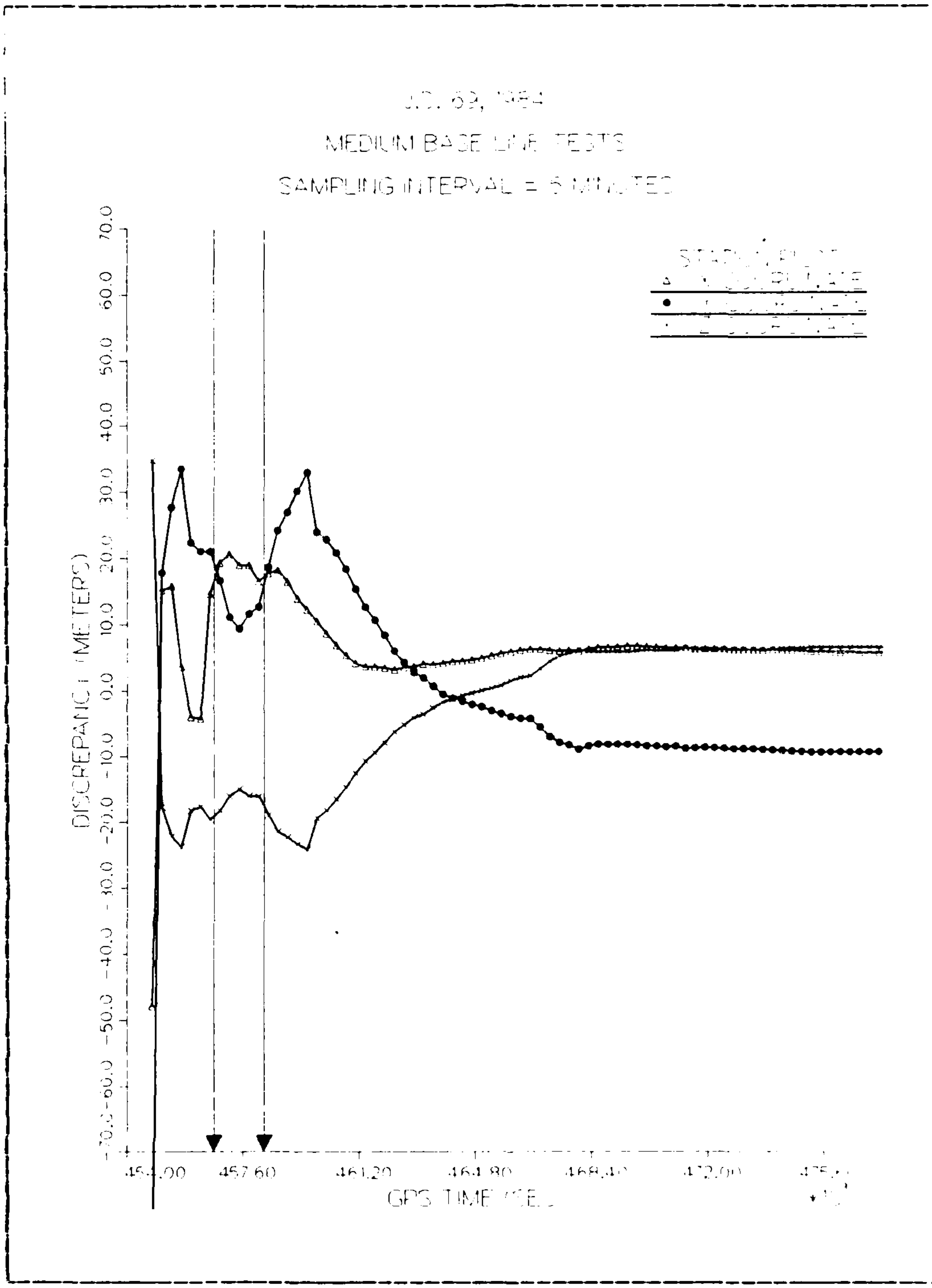

Figure 4.8 WGS-72 Coordinate Discrepancies

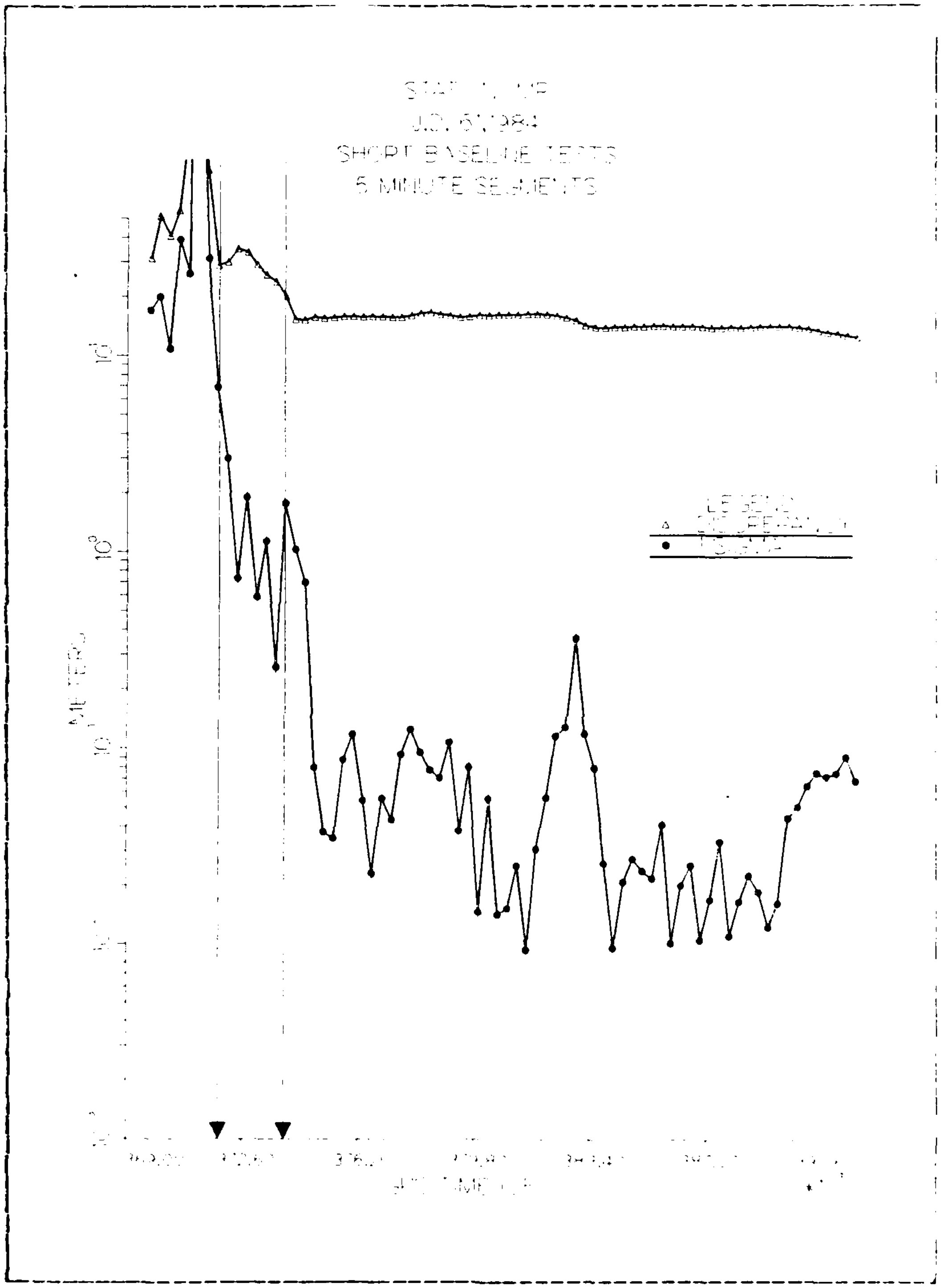

Figure 4.9   Discrepancies and Standard Errors

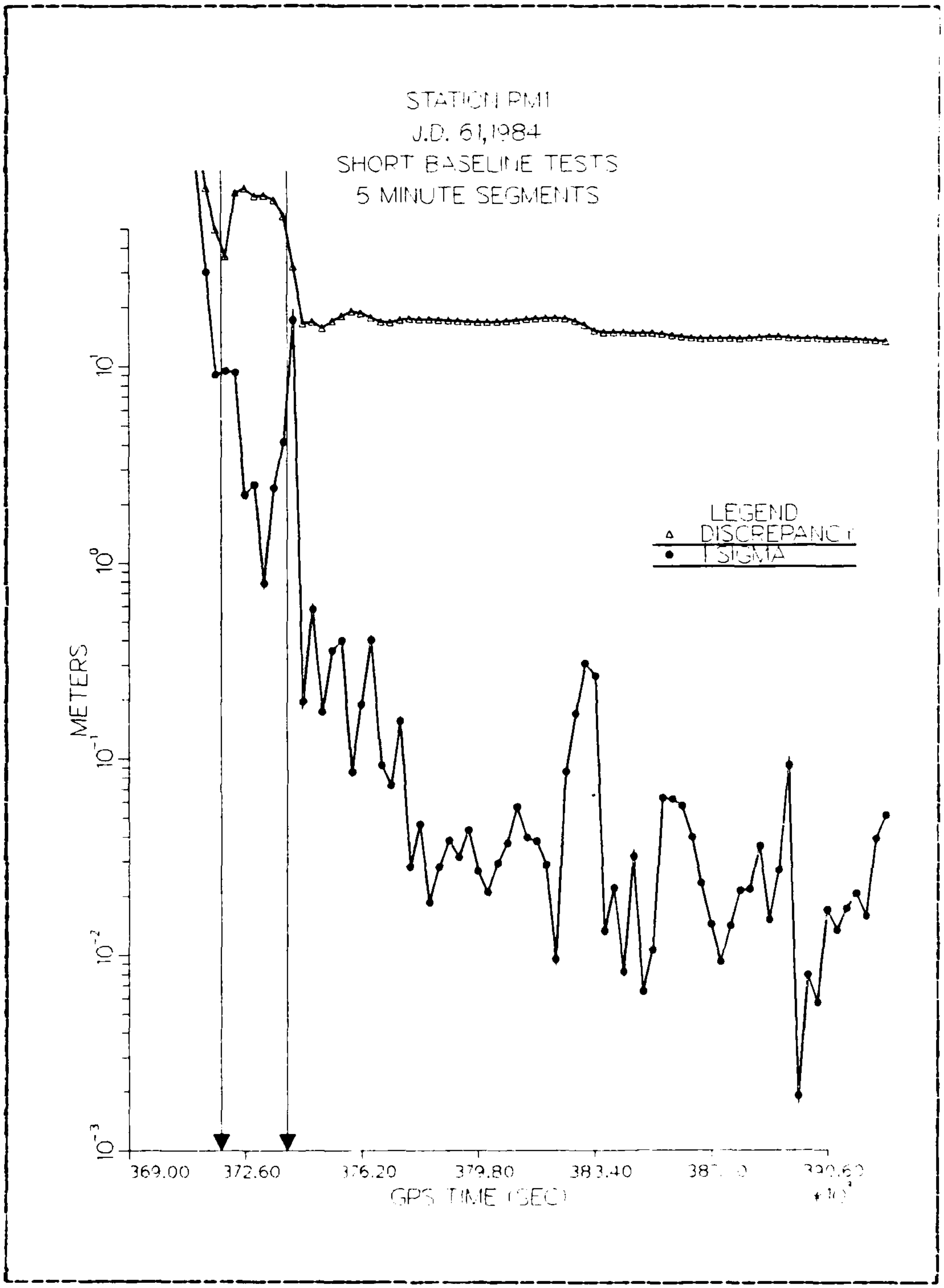

Figure 4.10 Discrepancies and Standard Errors

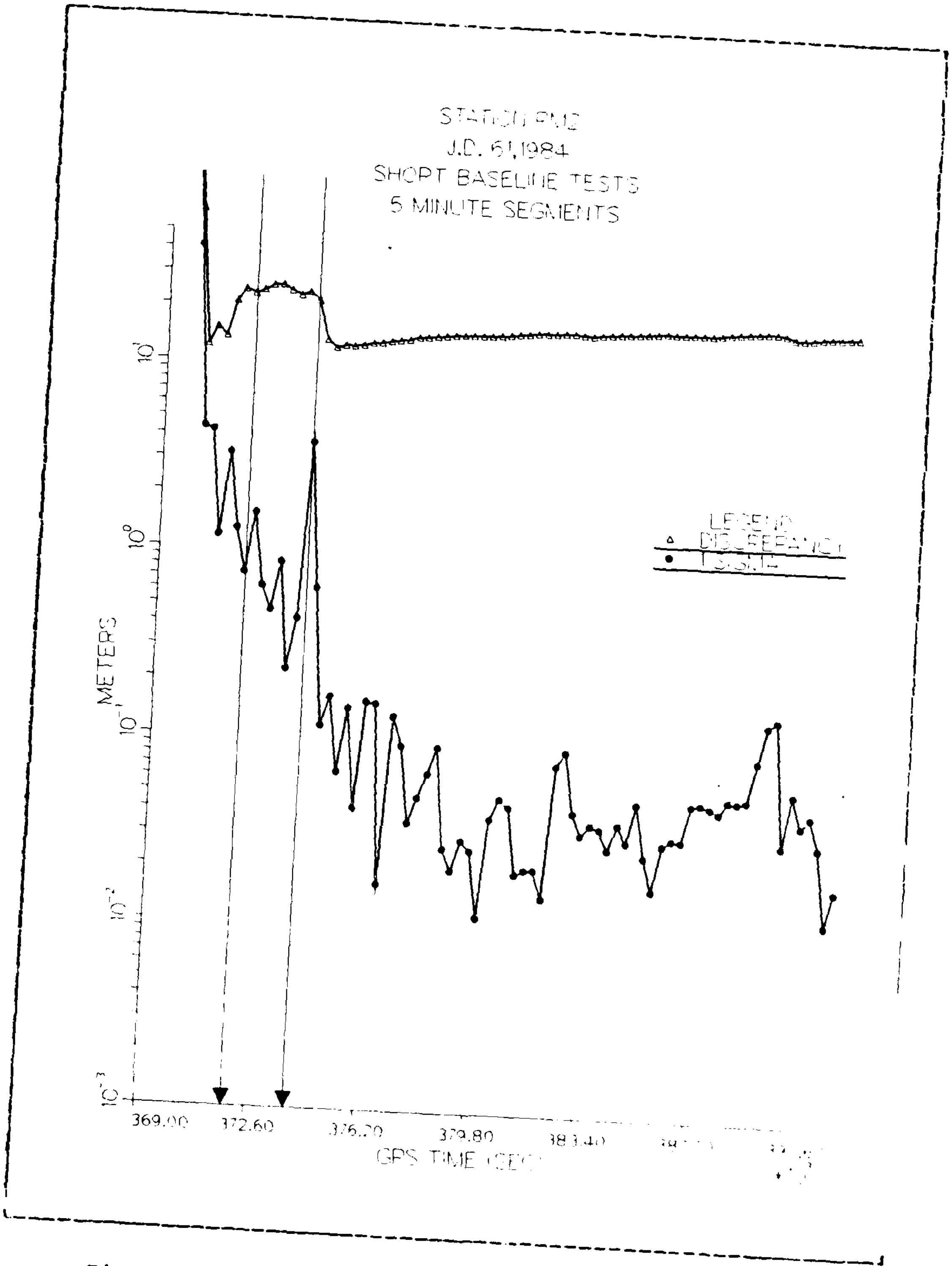

Figure 4.11 Discrepancies and Standard Errors

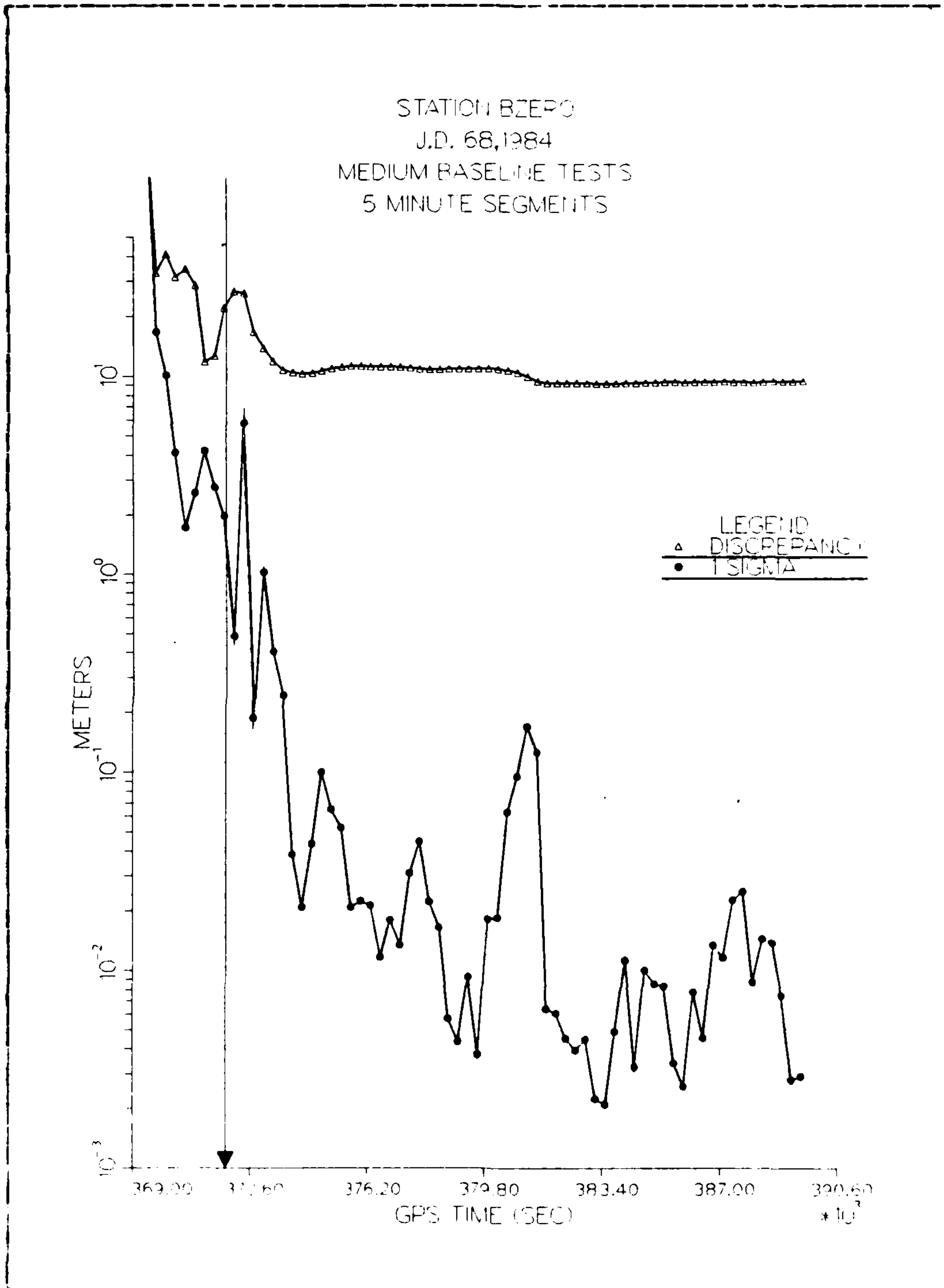

Figure 4.12 Discrepancies and Standard Errors

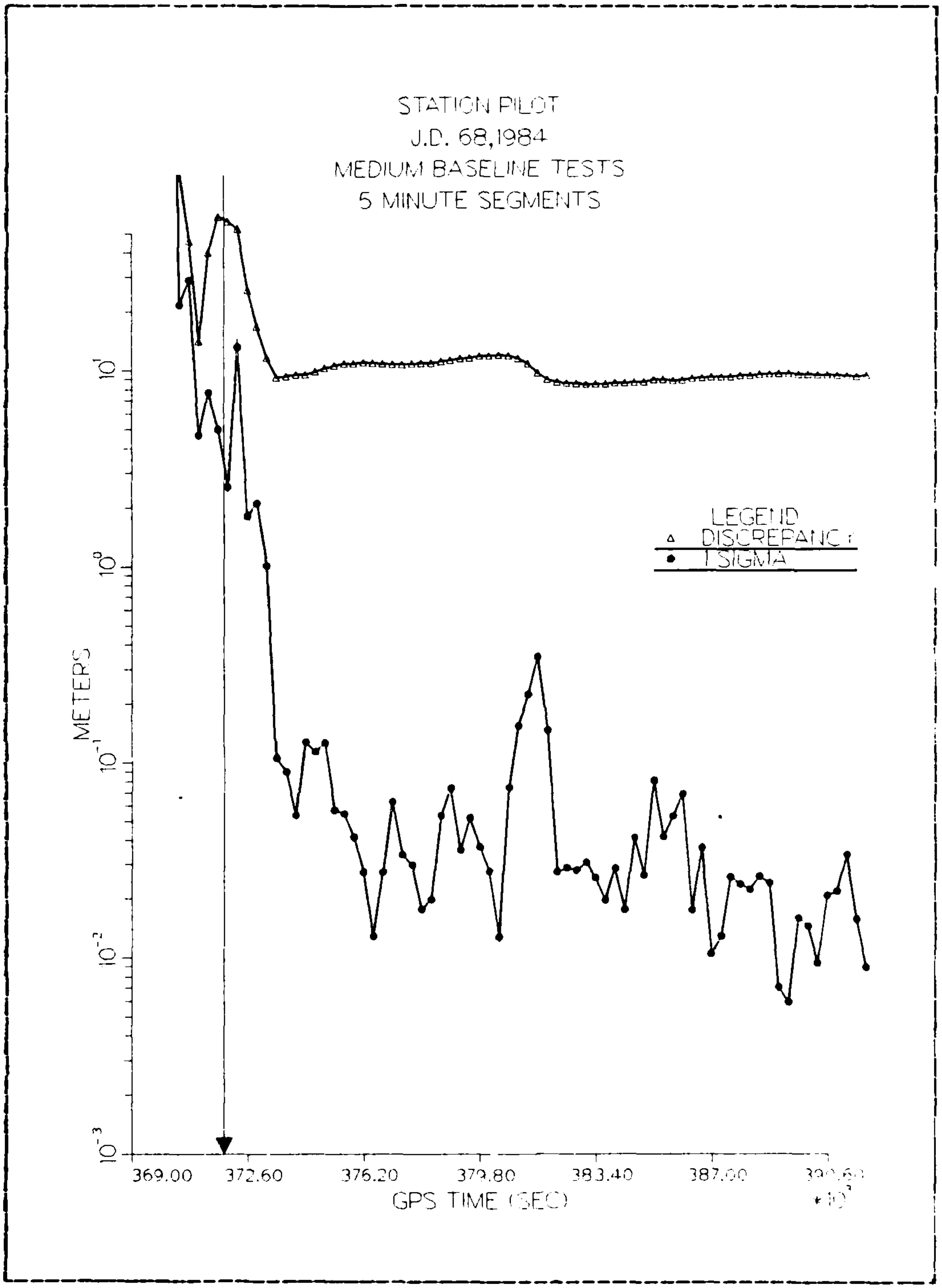

Figure 4.13 Discrepancies and Standard Errors

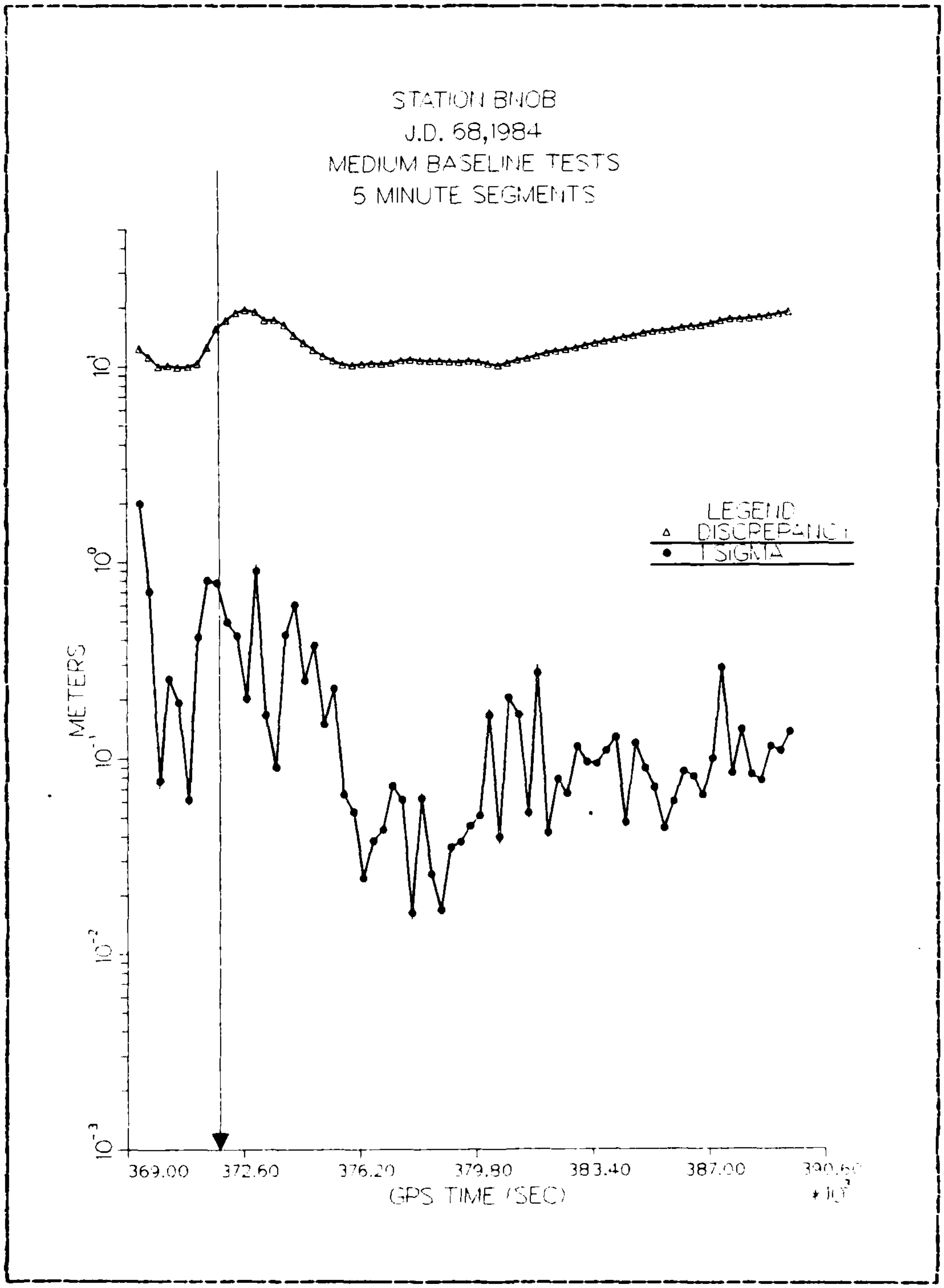

Figure 4.14 Discrepancies and Standard Errors

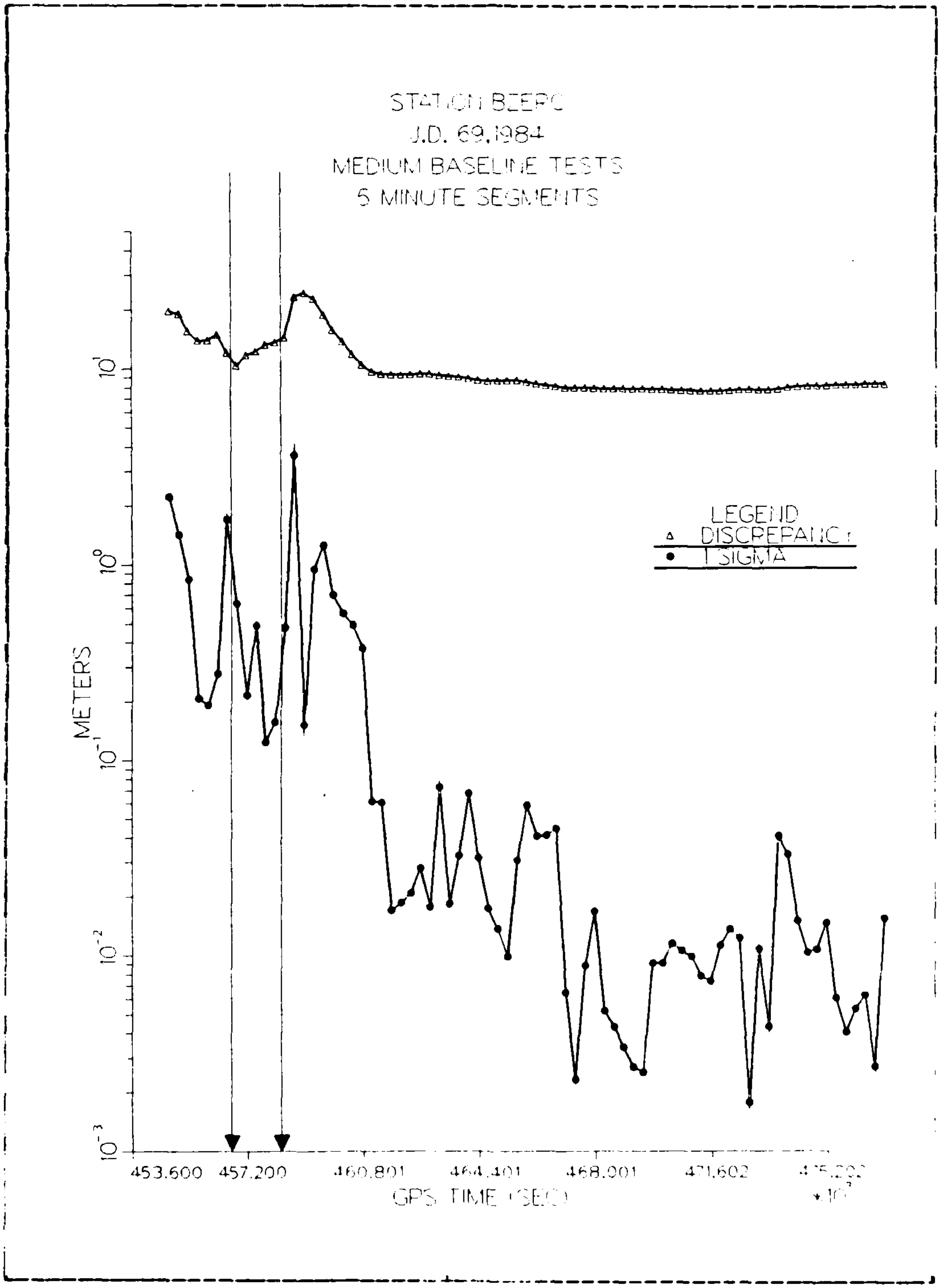

Figure 4.15 Discrepancies and Standard Errors

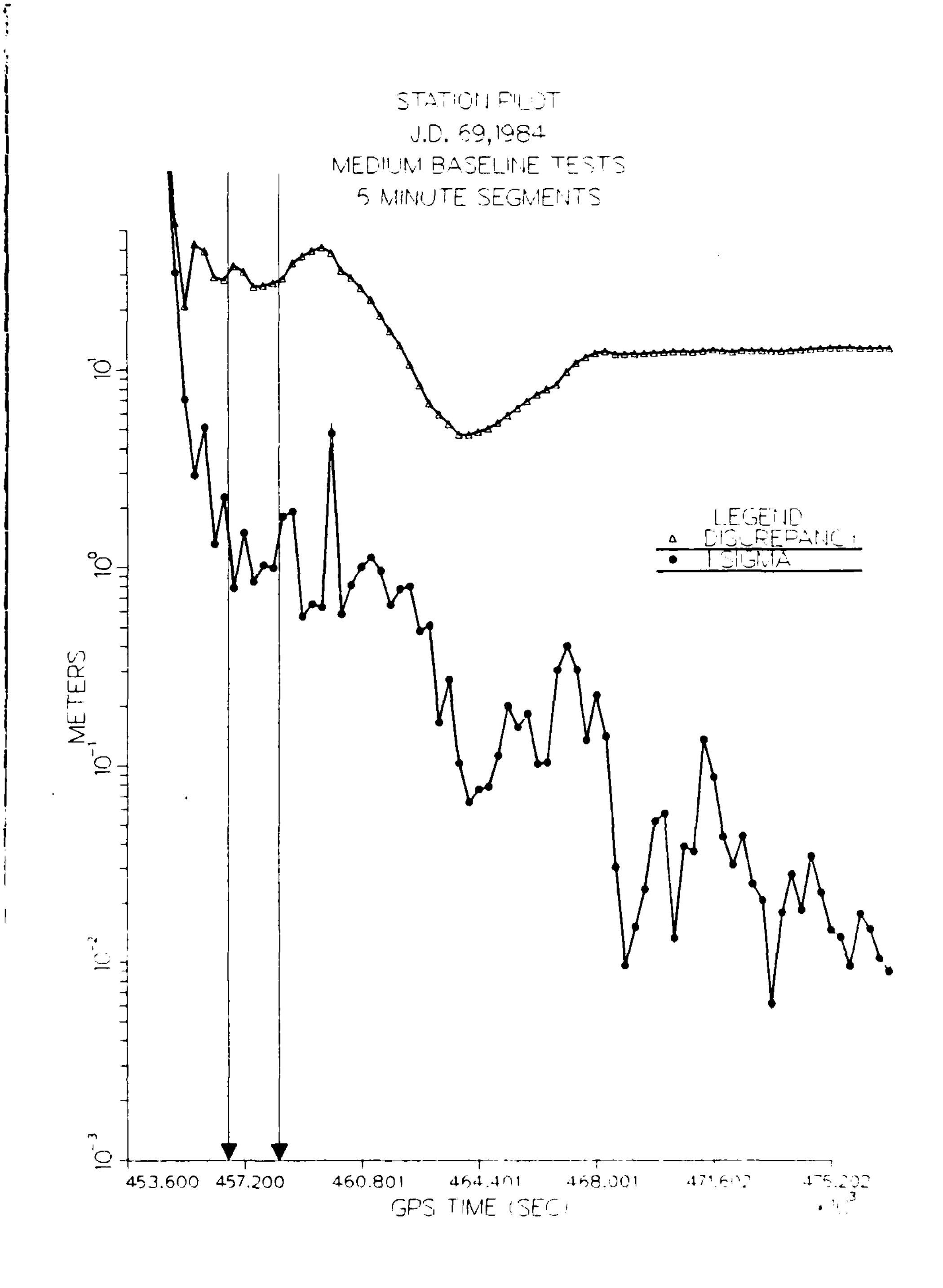

Figure 4.16 Discrepancies and Standard Errors

solutions are not consistent at all stations during the same day (Figs. 4.17 - 4.23). The discrepancies in the lengths of sides JMR-RM2 and RM1-RM2 are relatively small near time tag 382632; however, the side-length discrepancy of JMR-RM1 at approximately the same time is relatively larger than other determinations of that side on day 61. The side-length discrepancies of JMR-RM2 and RM1-RM2 are -.044 and .037 meters at time tags 382632 and 382600, respectively. The discrepancy of JMR-RM1 at time tag 382600 is .955 meters; whereas, the discrepancy is .476 meters at time tag 386400. Therefore, the most accurate side-length determinations do not necessarily occur at approximately the same time for all three sides.

The most accurate side-length determinations do not necessarily occur when the magnitudes of the point position discrepancy vectors of two stations are nearly the same because of differences in the directions of the discrepancies. The side-length discrepancies determined on day 68 for the side BZERO-BNOB illustrate this point (Fig. 4.21). The point position discrepancies for stations BZERO and BNOB are 10.889 and 10.816 meters at time tag 377808 and the side-length discrepancy is -.151 meters. At time tag 384408, the side-length discrepancy is -.036 meters and the magnitudes of the point position discrepancies are 9.295 and 14.053 meters. The side-length discrepancy is smaller at the later time tag even though the difference in the magnitudes of the point position discrepancies are greater at that time.

D. AVERAGING RESULTS

1. Determination of the Method of Averaging

Two averaging schemes were used to arrive at mean position discrepancies (Sect. III E). The means and

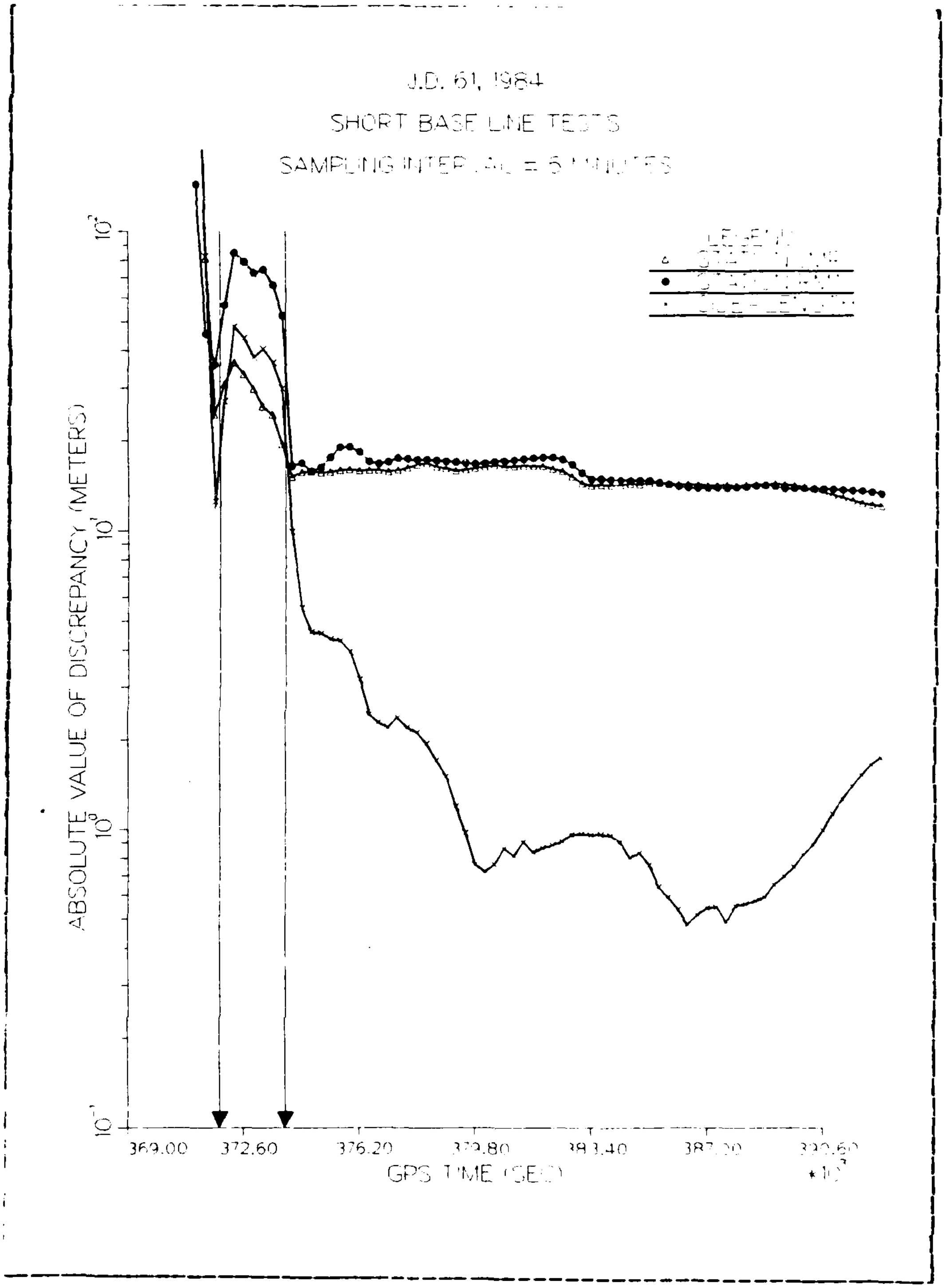

Figure 4.17 Point Position and Side-length Discrepancies

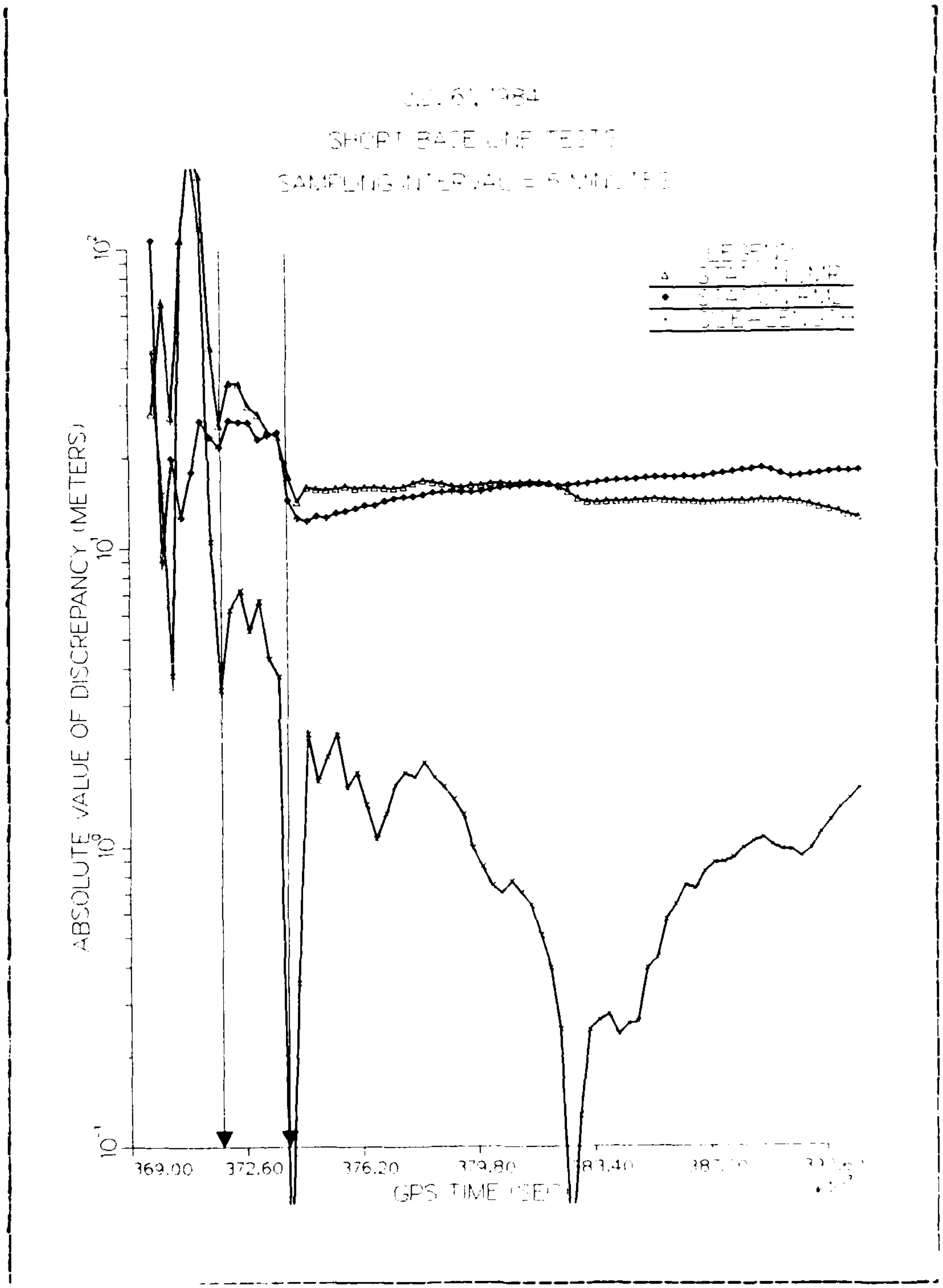

Figure 4.18   Point Position and Side-length Discrepancies

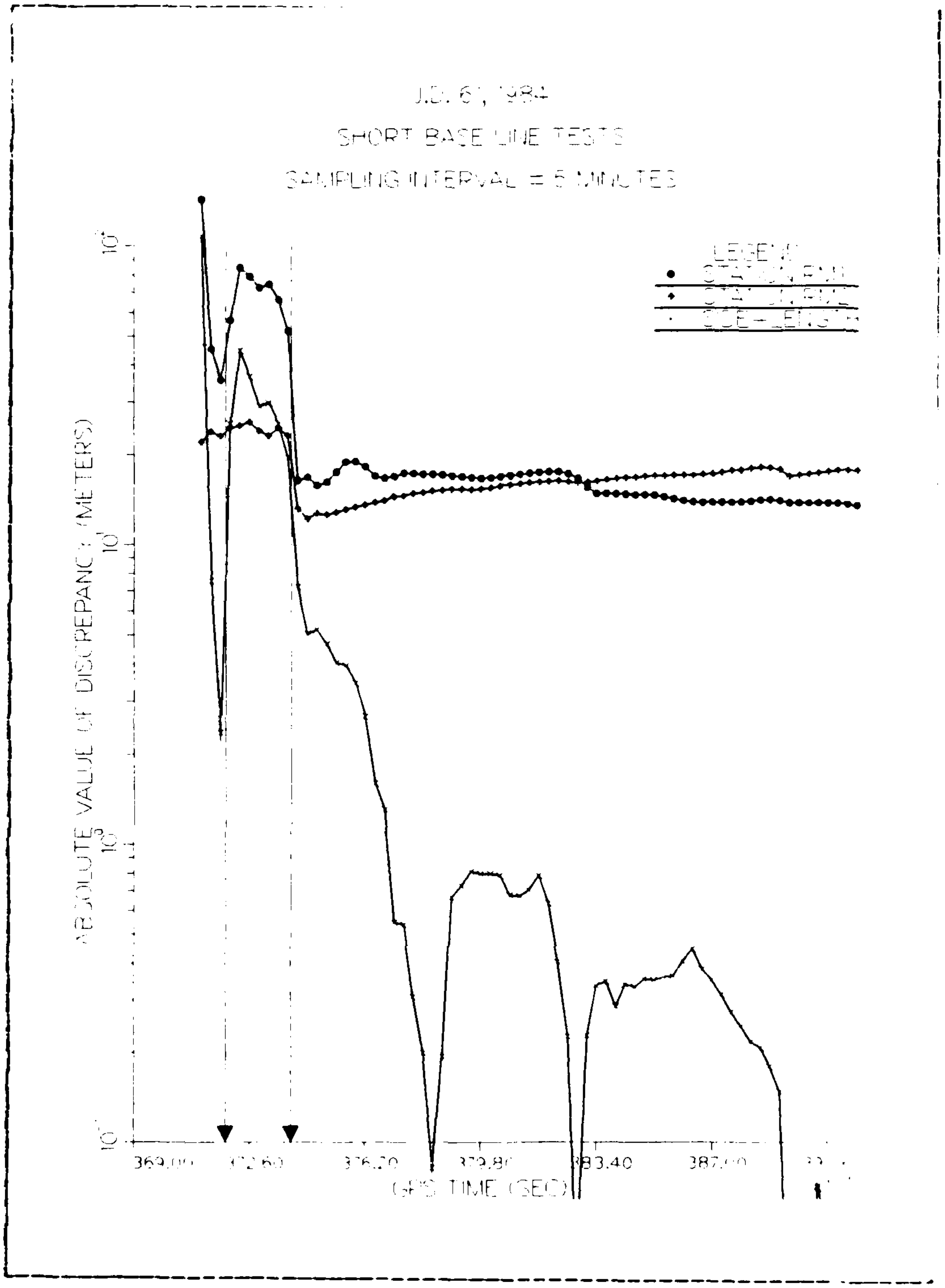

Figure 4.19 Point Position and Side-length Discrepancies

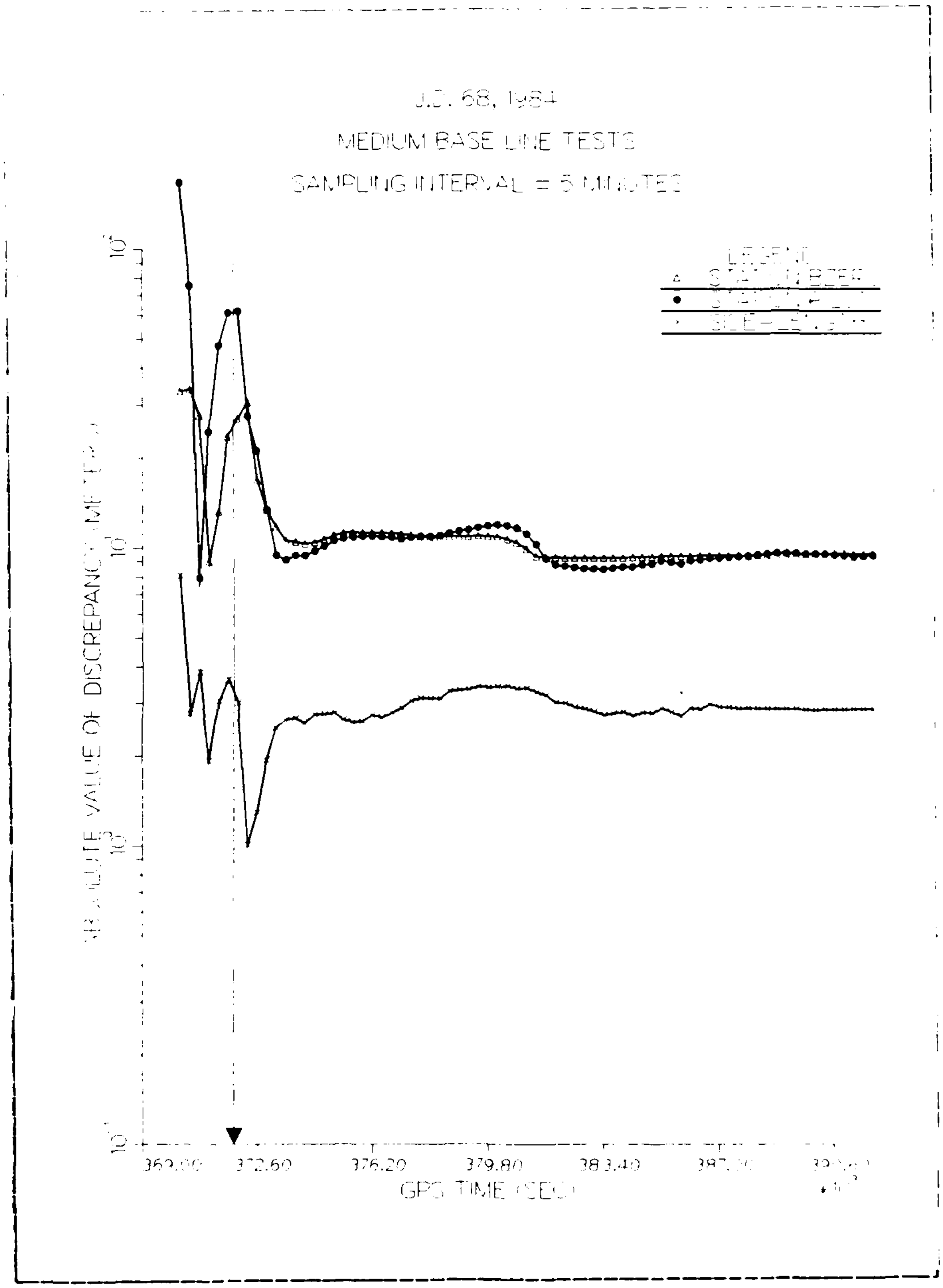

Figure 4.20 Point Position and Side-length Discrepancies

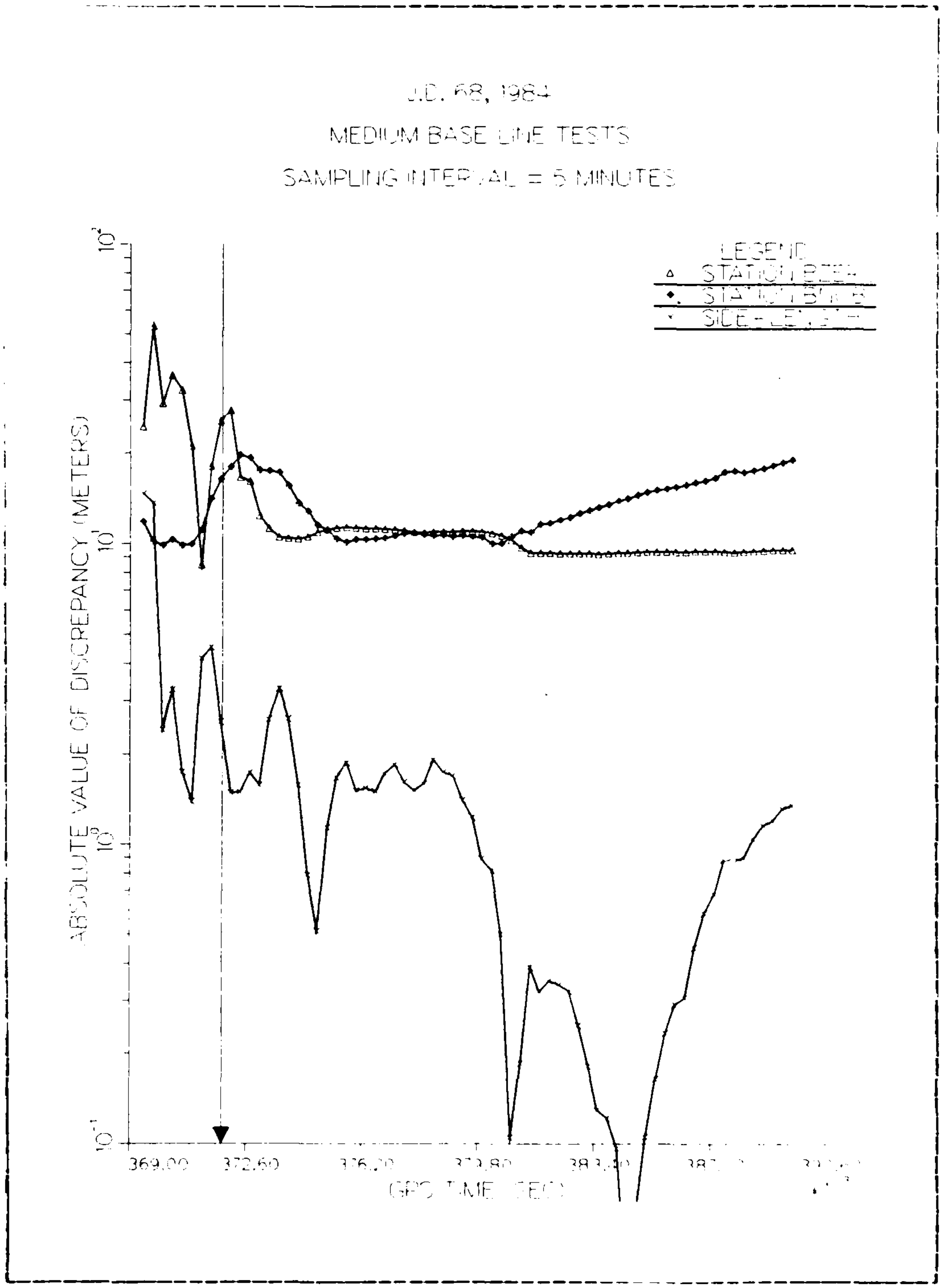

Figure 4.21 Point Position and Side-length Discrepancies

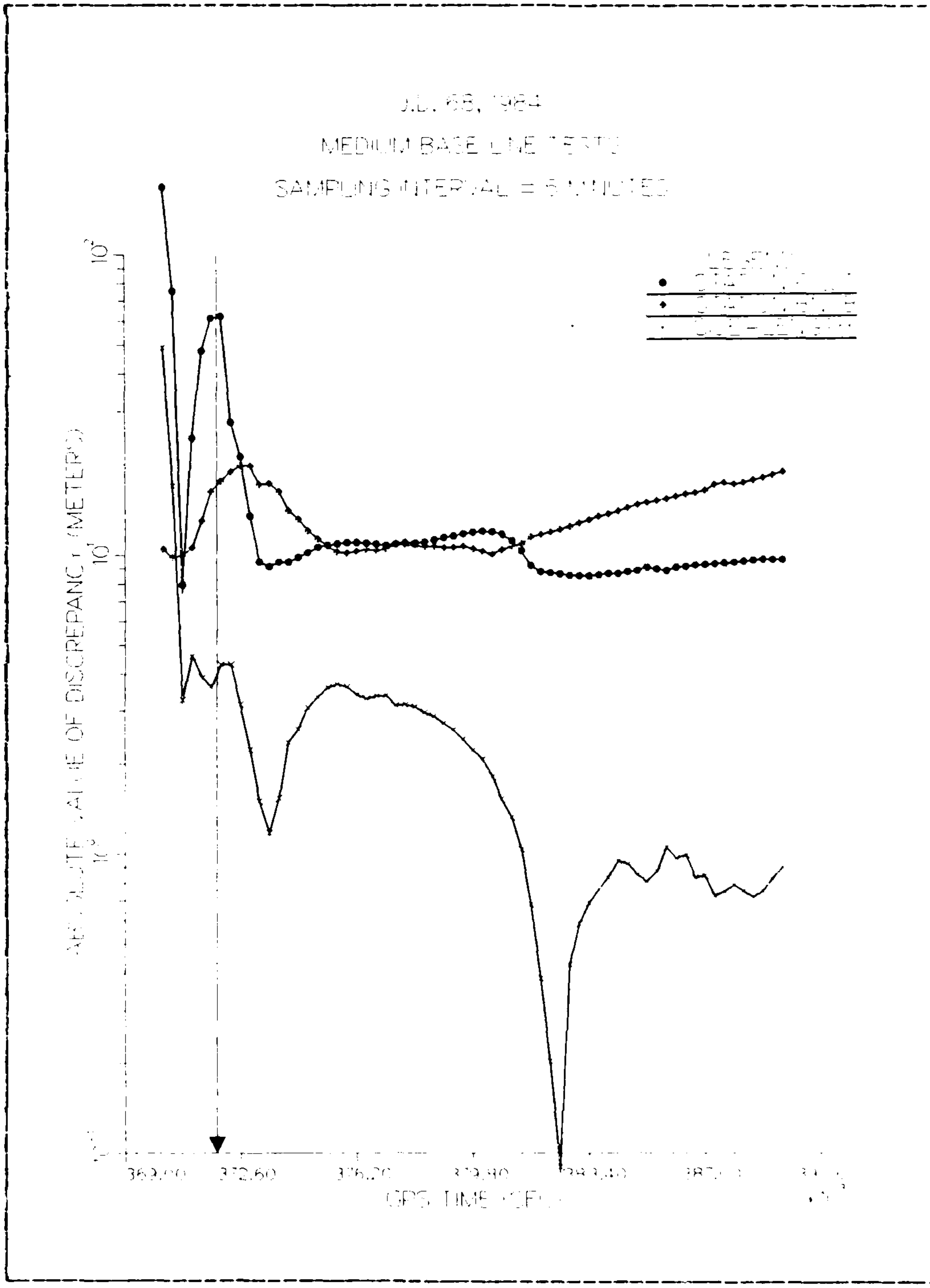

Figure 4.22   Point Position and Side-length Discrepancies

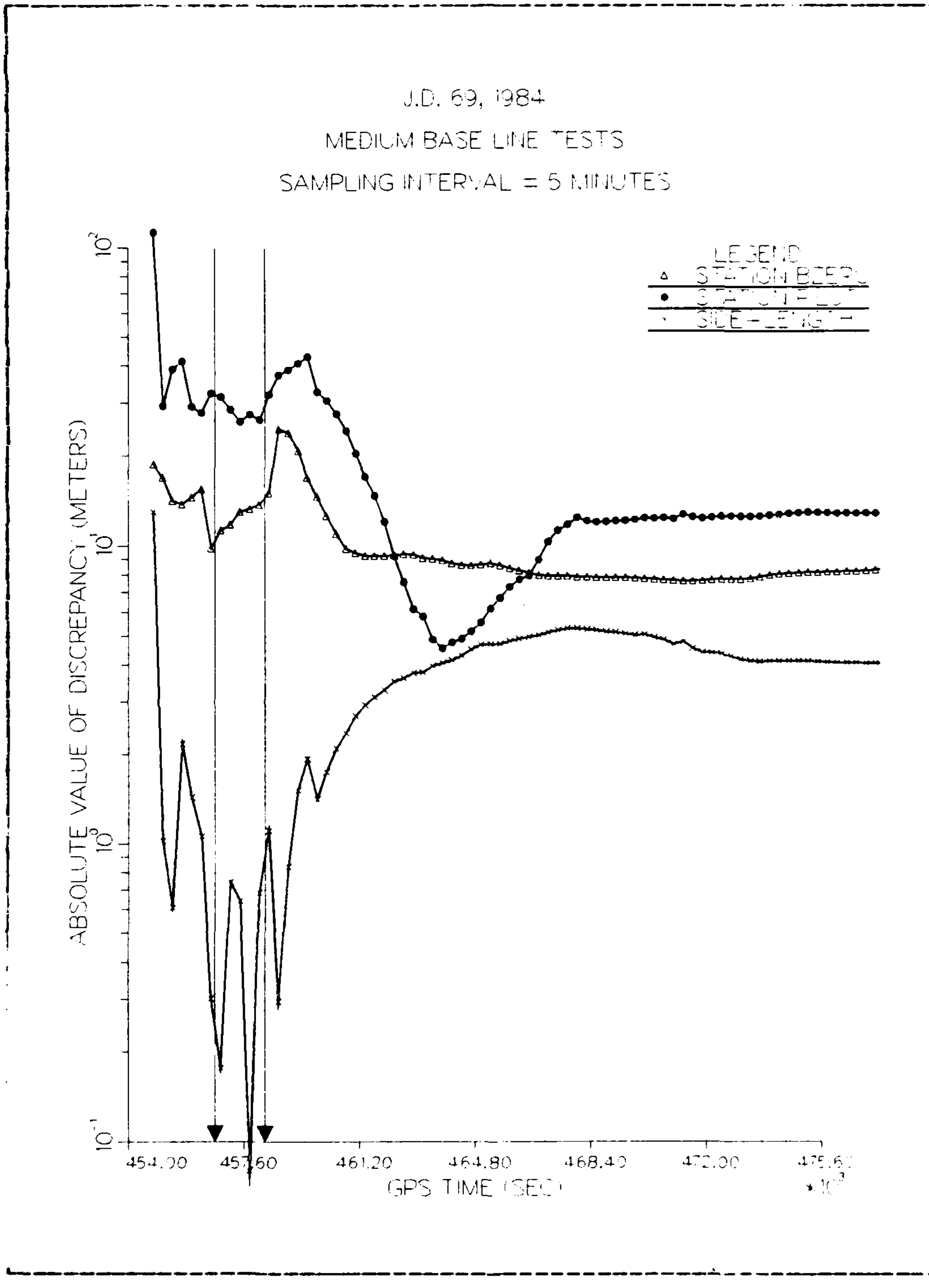

Figure 4.23 Point Position and Side-length Discrepancies

standard errors of discrepancies were computed for the X, Y, and Z coordinates and the absolute values of the total point position discrepancies (Tabs. VIII and IX).

The standard errors of the point position discrepancies for the solutions that were averaged beginning two hours after the initial solutions are, in general, smaller than those that were determined using all solutions beginning one hour after the initial solutions. The average standard error of the absolute value of the point position discrepancies for all pairs of determinations is 2.302 meters using the former averaging method, compared to 1.422 meters using the latter averaging method. Much of the difference between these two standard errors can be attributed to the relatively large point position discrepancies computed for stations BZERO and PILOT on day 69 between the first and second hours after the initial solutions (Figs. 4.15 and 4.16). Neglecting stations BZERO and PILOT on day 69, the average of all standard errors of the point position discrepancies are 1.657 meters and 1.333 meters for the two different averaging methods.

The elimination of the real-time solutions recorded between one hour and two hours after the start of data acquisition results in smaller standard errors of the point position discrepancies in the averaging process. The remainder of the analysis uses the mean coordinates determined by the averaging method in which only the real-time solutions recorded two hours after the initial solutions are used (Tab. IX).

2. WGS-72 Results

The Y coordinate discrepancies are larger than the discrepancies of X and Z coordinates at all stations with the exception of those at station BZERO on day 69. The mean observed X coordinates are consistently different from the

TABLE VIII

Means and Sigmas Beginning One Hour After Initial Solutions

J.D.	Station	X mean Sigma X	Y mean Sigma Y	Z mean Sigma Z	Point Position	Sample Size
61						
	JMR	6.677 1.242	-12.696 1.558	3.196 1.282	14.834 1.244	
	RM1	5.178 0.688	-13.512 1.927	5.371 0.685	15.495 1.667	1518
	JMR	7.502 3.356	-11.648 4.593	2.426 3.296	15.372 2.178	
	RM2	6.205 2.574	-12.186 5.639	4.789 4.619	16.274 2.197	1564
	RM1	5.162 0.700	-13.623 1.900	5.405 0.682	15.600 1.632	
	RM2	5.588 1.165	-13.548 1.375	5.794 2.707	16.019 1.512	1450
68						
	BZERO	5.806 0.725	-7.578 0.818	-2.623 1.226	10.006 0.761	
	PILOT	5.653 0.571	-7.877 1.107	1.090 1.240	9.860 1.029	1536
	BZERO	5.972 0.987	-7.337 1.452	-3.015 1.734	10.185 0.966	
	BNOB	6.060 1.625	-9.125 5.337	-0.563 5.919	13.348 2.872	1407
	PILOT	5.708 0.591	-7.916 1.178	0.992 1.298	9.924 1.086	
	BNOB	5.822 1.241	-9.777 4.527	0.058 5.324	13.126 2.745	1342
69						
	BZERO	6.629 1.379	-1.833 4.421	-4.441 3.758	9.464 3.607	
	PILOT	6.613 3.050	-1.030 11.727	-0.208 9.289	14.200 8.729	1664

Units are meters.

TABLE IX

Means and Sigmas Beginning Two Hours After Initial Solutions

J.D.	Station	X mean Sigma X	Y mean Sigma Y	Z mean Sigma Z	Point Position	Sample Size
61						
	JRM	6.288 0.561	-12.569 1.571	3.674 0.780	14.587 1.269	
	RM1	5.414 0.492	-12.937 1.657	5.333 0.689	15.045 1.492	1218
	JMR	6.291 0.551	-12.874 1.482	3.642 0.770	14.844 1.149	
	RM2	5.315 0.810	-14.004 0.369	6.578 1.846	16.454 1.056	1264
	RM1	5.407 0.505	-13.043 1.645	5.374 0.688	15.150 1.469	
	RM2	5.367 0.818	-14.069 0.293	6.950 1.481	16.650 0.889	1150
68						
	BZERO	5.513 0.411	-7.769 0.755	-2.074 0.530	9.780 0.652	
	PILOT	5.432 0.317	-7.862 1.193	1.585 0.764	9.736 1.072	1236
	BZERO	5.600 0.578	-7.793 0.795	-2.267 0.739	9.908 0.753	
	BNOB	5.476 0.697	-11.461 2.637	1.997 3.454	13.298 2.802	1107
	PILOT	5.461 0.337	-7.910 1.293	1.552 0.827	9.795 1.157	
	BNOB	5.480 0.715	-11.712 2.510	2.414 3.114	13.482 2.787	1042
69						
	BZERO	6.262 0.169	-3.504 1.523	-3.053 2.073	8.197 0.501	
	PILOT	5.717 0.940	-6.001 4.678	3.690 4.085	10.657 2.860	1364

Units are meters.

given X coordinates by approximately 5 to 6 meters at all stations on all days of data acquisition having an average standard error of .564 meters for all determinations. The Z coordinate has smaller discrepancies at all stations on days 68 and 69 compared to the other coordinates. The average standard errors of the Y and Z coordinate discrepancies for all determinations are 1.600 and 1.560 meters, respectively (Tab. IX).

The mean point position discrepancies in the WGS-72 Cartesian coordinate system range between 16.650 meters at station RM2 on day 61 and 8.197 meters at station BZERO on day 69. The average of all the mean point position discrepancy determinations is 12.685 meters. The standard errors of the mean point position discrepancies range between .501 meters at station BZERO on day 69 and 2.802 meters at station BNOB on day 68, with an average value of 1.383 meters for all determinations (Tab. IX).

E. GEODETIC COMPARISONS

The observed WGS-72 coordinates of each station are computed by subtracting the observed discrepancies from the given coordinates. The observed WGS-72 Cartesian coordinates are then transformed to NAD-27 geodetic coordinates using a modified version of NGS's D035-41 transformation program.

1. Discrepancies of Point Position Determinations

The point position discrepancies of all pairs of determinations are computed for the NAD-27 coordinates (Tab. X). Azimuths are measured from north. The average point position discrepancy is -.08336 seconds of latitude, -.26088 seconds of longitude, and +9.391 meters in ellipsoid height. The horizontal position discrepancies of the observed point

TABLE X

Geodetic and Horizontal Point Position Discrepancies

J.D.	Sta.	N. Lat. (seconds	W. Long. of arc)	Ht. (m.)	Horizontal Discrepancy Dist. (m.)	Horizontal Discrepancy Azimuth
61						
	JRM	-.08777	-.29658	+11.875	8.367	108° 50' 45".00144
	RM1	-.04916	-.26612	+13.129	7.265	102° 01' 38".53263
	JMR	-.09363	-.29824	+12.118	8.469	109° 54' 15".96103
	RM2	-.03192	-.26774	+14.682	7.216	97° 49' 45".00671
	RM1	-.04977	-.26633	+13.240	7.274	102° 09' 46".35205
	RM2	-.02242	-.27004	+14.920	7.243	95° 28' 11".02402
68						
	BZERO	-.17237	-.24400	+4.953	8.403	129° 10' 24".21298
	PILOT	-.07071	-.24063	+6.903	6.797	108° 40' 55".77329
	BZERO	-.17798	-.24727	+4.866	8.580	129° 41' 58".04469
	BNOB	-.11848	-.25994	+10.189	7.844	117° 43' 08".57467
	PILOT	-.07237	-.24207	+6.924	6.850	108° 59' 02".11371
	BNOB	-.11089	-.26138	+10.614	7.772	116° 03' 42".13414
69						
	BZERO	-.12874	-.25019	+.725	7.767	120° 41' 22".07545
	PILOT	+.01911	-.24185	+6.333	6.498	84° 48' 17".17181

positions for all determinations range between 6.498 meters at station PILOT on day 69 and 8.530 meters at station BZERO on day 68. The average distance discrepancy along the ellipsoid is 7.596 meters. The azimuths from the given positions to the observed positions range between 129° 41' 58".04469 at station BZERO on day 68 and 84° 48' 17".17181 at station PILOT on day 69. The observed positions have an average azimuth of 109° 25' 56".5699 from the given positions.

2. Discrepancies of Point Positions for Entire Recording Sessions

There are two determinations of point position discrepancies on days 61 and 68 as a result of comparing pairs of stations in the computations. An estimate of the repeatability of an entire recording session can be calculated by first averaging the two point position discrepancies for each station then computing the standard error of the eight determinations.

The average discrepancies of entire recording sessions are -.07980 seconds of latitude and -.25903 seconds of longitude with standard errors of .03976 and .01764 seconds, respectively. The average height discrepancy is 8.658 meters above the station with a standard error of 4.748 meters. The average horizontal distance discrepancy is 7.538 meters with a standard error of .714 meters.

3. Relative Position Comparisons

The distances and azimuths between pairs of stations are computed for both the given coordinates and the observed coordinates by the inverse computation. The differences of two are computed by subtracting the given distances and azimuths from the observed values (Tab. XI). Six of the seven observed side-lengths are shorter than the distances

TABLE XI

Discrepancies of Observed Distances and Azimuths

I.D.	Side	Dist.(m.)	Azimuth
61			
	JRM-RM1	1.397	-44' 44".2009
	JMR-RM2	-0.006	-4° 17' 40".3464
	RM1-RM2	-0.231	-1° 14' 30".5102
58			
	BZERO-PILOT	-3.128	-1".24259
	BZERO-BNOB	-0.428	-26".09039
	BNOB-PILOT	-0.774	9".49565
59			
	BZERO-PILOT	-4.556	-1".05927

computed from the given coordinates. In the short base line tests, the differences in azimuth are of the order of degrees compared to differences of the order of seconds of arc in the medium base line tests. In general, the azimuth differences decrease as the side-length differences increase in both the short base line and medium base line tests.

4. Relative Position Discrepancies

Relative positioning is used to determine an unknown position relative to the position of a known station. The direct computation calculates the coordinates of a position given the coordinates of a known position and the distance and azimuth to the unknown position. The distance and azimuth between pairs of observed positions are used in the calculation. Stations JMR and RM1 are taken as fixed in the short base line tests and the positions of RM1 and RM2 are calculated. Stations BZERO and BNOB are used to locate stations BNOB and PILOT in the medium base line tests. The

discrepancies of the calculated positions are computed in terms of latitude, longitude, elevation, distance, azimuth, and relative accuracy between stations (Tab. XII). The elevation discrepancies are determined by computing the difference of the height discrepancies between pairs of point position solutions.

Relative position determinations differ from the given positions by an average of 1.452 meters in the short base line tests and 2.712 meters in in the medium base line tests. The relative accuracies between stations range between 1:13 for the side JMR-RM1 on day 61 and 1:17,418 for the side BNOB-PILOT on day 68. The average relative accuracy of the medium base line tests is 1:9,712. Station PILOT was determined to relative accuracies of 1:8,139 and 1:5,593 with respect to station BNOB on subsequent days.

The data acquired in the short base line tests provide useful information in the absolute position analyses; however, this scenario is not a practical application of relative position determinations. It is not justifiable to measure distances of the order of thirty meters with such expensive equipment when the distances can be measured accurately with steel tape or other inexpensive equipment.

TABLE XII

Discrepancies in Relative Position Determinations

Station	N.Lat. (sec.	W.Long. of arc)	Ht. (m.)	Horizontal Discrepancy Dist. (m.)	Horizontal Discrepancy Azimuth	Relative Accuracy
J.D. 61						
RM1	.03861	.03046	+1.254	1.440	214° 22' 22".77900	1:18
RM2	.06171	.03050	+2.564	2.067	203° 11' 48".35112	1:13
RM2	.02735	-.00371	+1.680	.848	173° 17' 31".41035	1:44
J.D. 68						
PILOT	.10167	.00333	+1.950	3.132	181° 37' 49".49395	1:8,139
BNOB	.05950	-.01291	+5.323	1.864	169° 19' 57".15833	1:7,697
PILOT	.03852	.01944	+3.690	1.295	203° 40' 53".10476	1:17,418
J.D. 69						
PILOT	.14785	.00831	+5.608	4.558	182° 47' 47".02537	1:5,593

V. CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the medium base line tests, the real-time solutions of the TI4100/GEOSTAR are capable of establishing relative positions to Third-order, Class II standards. Two receivers, one located at a known position and the other separated by 14 to 26 kilometers, can locate horizontal control in real-time. This assumes five hours of visibility of four satellites and a means for the output of a solution based on the averaging of real-time solutions recorded at 12-second intervals.

It is found that relative positioning using GPS is more accurate than absolute point positioning. The average distance discrepancy of the absolute position determinations is 7.538 meters compared to relative position averages of 1.452 meters in the short base line tests and 2.712 meters in the medium base line tests. The absolute point position determinations have a one sigma repeatability of .714 meters in distance discrepancy. The relatively high repeatability of absolute point position determinations resulted in relative position accuracies of 1:9,712, on average, for distances of 14 to 26 kilometers.

Third-order, Class II accuracies can be obtained with the GEOSTAR Receiver in real-time. A typical operational unit consists of two, 2-man teams; each team supplied with the GEOSTAR field set. One team sets an antenna over a known position and the other team locates at the point to be surveyed. Both receivers should gather data simultaneously during the periods of satellite visibility (during Phase II testing). The teams should agree to begin the averaging algorithm at a predetermined time tag, preferably a short time after the uploads to the satellites. Satellite upload times can be requested beforehand from Vandenburg AFB.

Additional averaging methods should be explored. In regard to the real-time solutions, averaging analyses could be performed to determine the amount of data acquisition time required to achieve certain accuracies. An analysis of this nature would be important for special military applications where an accurate position is required in less than five hours of receiver operation.

In the Fall 1984 the GEOSTAR will undergo hardware and software modification before full-scale production. It is planned that the software will be modified to include real-time solutions of short time-interval observations; these solutions will be different from existing real-time solutions based on a cumulative least squares method. [Ref. 22] Relative position determinations using the real-time solutions should improve with the new software because the solutions of two receivers can be compared simultaneously with no influence from preceding solutions.

APPENDIX A

GPS USER-TAPE READ-WRITE PROGRAM

```
C***********************************************************
C
C       THIS PROGRAM IS A SLIGHTLY MODIFIED VERSION OF THE
C   EXAMPLE INPUT PROGRAM CONTAINED IN "A STANDARDIZED
C   EXCHANGE FORMAT FOR NAVSTAR GPS GEODETIC DATA" BY
C   BY V. DAN SCOTT AND J. GARRY PETERS, APPLIED RESEARCH
C   LABORATORIES, THE UNIVERSITY OF TEXAS AT AUSTIN, MARCH
C   10, 1983. THIS PROGRAM CAN BE EASILY CHANGED TO READ
C   AND WRITE ANY DATA TYPE ON GPS USER-TAPES SUPPLIED BY
C   NSWC. TO WRITE ALTERNATIVE DATA TYPES, CONSULT THE
C   ABOVE PUBLICATION TO DETERMINE THE DATA TYPES THAT
C   CORRESPOND TO THE DATA OF INTEREST. EXAMPLE: TO PRINT
C   OUT EPHEMERIS INFORMATION (DATA TYPE 4110), CHANGE
C   THE GO TO STATEMENT FOLLOWING THE IF STATEMENT THAT
C   TESTS FOR THIS DATA TYPE BELOW TO TRANSFER CONTROL
C   TO WRITE STATEMENTS WITH THE PROPER FORMAT. THE
C   FORMATS OF ALL DATA TYPES ARE GIVEN IN THE ABOVE
C   PUBLICATION. THE JCL FOR THIS PROGRAM IS FOR AN
C   IBM 370 MODEL 3033. THE TAPES ARE RECORDED WITH 1600
C   BPI, A LOGICAL RECORD LENGTH OF 80, A BLOCKSIZE OF
C   6400, AND ASCII CODED.
C
C***********************************************************
C
//RAKOW JOB (1643,0130),'RAKOWSKY',CLASS=F
//*MAIN ORG=NPGVM1.1643P
//  EXEC FORTXCLG
//FORT.SYSIN DD *
C
C
```

```
      REAL*8 TTAG,X,Y,Z,SIGT
C
      INTEGER ICN,IREP,ICONTR,NREP,INDEX,DTYPE,JUNK,ASTER,
     * BLANK,SENT,PLUS,CHARE,CHARF,CHARI,NRID
      REAL SIGX,SIGY,SIGZ,SKIP
C
      DATA ASTER/'*'/,PLUS/'+'/,CHARE/'E'/,CHARF/'F'/,
     * CHAR/'I'/,BLANK/' '/,SENT/'$'/
C
      DIMENSION ICONTR(19)
C
 100  CONTINUE
      READ(1,10) ICN,IREP,ICONTR
  10  FORMAT(A1,I3,19I4)
C
 120  CONTINUE
      IF(ICN.EQ.ASTER) GO TO 150
      IF(ICN.EQ.PLUS) GO TO 100
      IF(ICN.EQ.CHARE) GO TO 100
      IF(ICN.EQ.CHARF) GO TO 500
      IF(ICN.EQ.CHARI) GO TO 500
      IF(ICN.EQ.SENT) GO TO 500
C
 150  CONTINUE
C
      IF(IREP.EQ.0) IREP=1
      NREP=0
      ICN=BLANK
C
 200  CONTINUE
C
      INDEX=0
      NREP=NREP+1
      IF(IREP.LT.0) GO TO 300
      IF(NREP.GT.IREP) GO TO 100
```

```
      GO TO 300
C
 300  CONTINUE
C
      IF(ICN.NE.BLANK) GO TO 120
      INDEX=INDEX+1
      IF(INDEX.GT.19) GO TO 200
      DTYPE=ICONTR(INDEX)
      IF(DTYPE.EQ.0) GO TO 200
C
      IF(DTYPE.EQ.910) GO TO 204
      IF(DTYPE.EQ.920) GO TO 201
      IF(DTYPE.EQ.1010) GO TO 204
      IF(DTYPE.EQ.1020) GO TO 205
      IF(DTYPE.EQ.1030) GO TO 204
      IF(DTYPE.EQ.1040) GO TO 203
      IF(DTYPE.EQ.1050) GO TO 204
      IF(DTYPE.EQ.1110) GO TO 204
      IF(DTYPE.EQ.1150) GO TO 202
      IF(DTYPE.EQ.2010) GO TO 201
      IF(DTYPE.EQ.2020) GO TO 201
      IF(DTYPE.EQ.2030) GO TO 201
      IF(DTYPE.EQ.2110) GO TO 203
      IF(DTYPE.EQ.2120) GO TO 201
      IF(DTYPE.EQ.2130) GO TO 201
      IF(DTYPE.EQ.2140) GO TO 201
      IF(DTYPE.EQ.2210) GO TO 202
      IF(DTYPE.EQ.2250) GO TO 201
      IF(DTYPE.EQ.2270) GO TO 201
      IF(DTYPE.EQ.3010) GO TO 202
      IF(DTYPE.EQ.3210) GO TO 201
      IF(DTYPE.EQ.3220) GO TO 201
      IF(DTYPE.EQ.3250) GO TO 201
      IF(DTYPE.EQ.4010) GO TO 201
      IF(DTYPE.EQ.4050) GO TO 201
```

```
      IF(DTYPE.EQ.4110) GO TO 204
      IF(DTYPE.EQ.4120) GO TO 202
      IF(DTYPE.EQ.4210) GO TO 203
      IF(DTYPE.EQ.4250) GO TO 202
      IF(DTYPE.EQ.4270) GO TO 202
      IF(DTYPE.EQ.5010) GO TO 201
      IF(DTYPE.EQ.6010) GO TO 6010
      IF(DTYPE.EQ.6020) GO TO 202
      IF(DTYPE.EQ.6100) GO TO 201
      IF(DTYPE.EQ.6110) GO TO 203
      IF(DTYPE.EQ.7010) GO TO 201
      IF(DTYPE.EQ.7110) GO TO 202
      IF(DTYPE.EQ.7120) GO TO 201
      IF(DTYPE.EQ.7210) GO TO 201
      IF(DTYPE.EQ.7220) GO TO 201
      IF(DTYPE.EQ.7230) GO TO 201
      IF(DTYPE.EQ.7240) GO TO 202
      IF(DTYPE.EQ.7250) GO TO 202
      IF(DTYPE.EQ.7260) GO TO 203
      WRITE(4,31)
   31 FORMAT('DATATYPE ERROR')
C
  201 CONTINUE
      READ(1,11) ICN
   11 FORMAT(A1)
      IF((ICN.NE.BLANK).AND.(ICN.NE.PLUS)) GO TO 120
      GO TO 300
C
  202 CONTINUE
      READ(1,11) ICN
      IF((ICN.NE.BLANK).AND.(ICN.NE.PLUS)) GO TO 120
      READ(1,11) NCN
      GO TO 300
C
  203 CONTINUE
```

```
      READ(1,11) ICN
      IF((ICN.NE.BLANK).AND.(ICN.NE.PLUS)) GO TO 120
      READ(1,11) NCN
      READ(1,11) NCN
      GO TO 300
C
 204  CONTINUE
      READ(1,11) ICN
      IF((ICN.NE.BLANK).AND.(ICN.NE.PLUS)) GO TO 120
      READ(1,11) NCN
      READ(1,11) NCN
      READ(1,11) NCN
      GO TO 300
C
 205  CONTINUE
      READ(1,11) ICN
      IF((ICN.NE.BLANK).AND.(ICN.NE.PLUS)) GO TO 120
      READ(1,11) NCN
      READ(1,11) NCN
      READ(1,11) NCN
      READ(1,11) NCN
      GO TO 300
C
 6010 CONTINUE
C
      READ(1,12) ICN,NRID,TTAG,X,Y
      IF((ICN.NE.BLANK).AND.(ICN.NE.PLUS)) GO TO 120
      READ(1,13) NCN,Z,SIGT,SIGX,SIGY,SIGZ,SKIP
      WRITE(4,14) TTAG,X,Y,Z
      WRITE(4,15) SIGX,SIGY,SIGZ
C
C  READ FORMATS
C
   12 FORMAT(A1,I2,8X,D22.15,D22.15,D17.10)
   13 FORMAT(A1,2D17.10,4E10.3)
```

```
C
C  WRITE FORMATS
C
  14   FORMAT(D22.15,D22.15,D17.10,D17.10)
  15   FORMAT(31X,D17.10,4X,E10.3,4X,E10.3)
C
       GO TO 300
 500   CONTINUE
       STOP
       END
C
C
//GO.FT01F001 DD UNIT=3400-3,VOL=SER=mytape,
//   DISP=(OLD,PASS),LABEL=(2,NL,,IN),
//   DCB=(RECFM=FB,LRECL=80,BLKSIZE=6400,DEN=3,OPTCD=Q)
//GO.FT04F001 DD DSN=MSS.S1643.FILENAME,UNIT=3330V,
//     DISP=(NEW,CATLG,DELETE),MSVGP=PUB4B,
//   DCB=(RECFM=FB,LRECL=80,BLKSIZE=6400)
/*
//
```

APPENDIX B

PROGRAM TO COMPUTE REAL-TIME SOLUTION DISCREPANCIES

```
C***********************************************************
C
C       THIS PROGRAM COMPUTES THE DIFFERENCES OF THE X, Y,
C   AND Z COORDINATES, THE TOTAL POINT POSITION DISCREP-
C   ANCIES, AND THE SIDE-LENGTH DISCREPANCIES FOR TWO
C   STATIONS AT COMMON GPS TIMES. THIS PROGRAM, IN EFFECT,
C   WRITES THE ABOVE DATA BEGINNING WITH THE FIRST REAL-
C   TIME SOLUTIONS OF EACH TAPE, THEN SPOOLS THE TAPE OF
C   THE EARLIER RECORDING SESSION TO CORRESPOND TO THE
C   GPS TIME OF THE TAPE THAT STARTED RECORDING AT A LATER
C   TIME. A CONVERSION OF THE GIVEN GEODETIC COORDINATES
C   TO WGS-72 CARTESIAN COORDINATES MUST FIRST BE DONE.
C   THESE VALUES ALONG WITH COMPUTED SIDE-LENGTH DISTANCE
C   ARE ENTERED BELOW FOLLOWING THE TYPE DEFINITIONS. THE
C   OUTPUT IS IN THE FORM: 'GIVEN VALUE - REAL-TIME
C   SOLUTION VALUE'.
C
C***********************************************************
C
//RAKOW JOB (1643,0130),'RAKOWSKY',CLASS=B
//*MAIN ORG=NPGVM1.1643P
//  EXEC FORTXCLG
//FORT.SYSIN DD *
C
      REAL*8 TTAG1,TTAG2,X1,X2,Y1,Y2,Z1,Z2,DELX,DELY,DELZ,
     *  DIST,DVALUE,SIGX1,SIGX2,SIGY1,SIGY2,SIGZ1,SIGZ2,
     *  DELDST,X1GIVN,X2GIVN,Y1GIVN,Y2GIVN,Z1GIVN,Z2GIVN,
     *  X1DIF,X2DIF,Y1DIF,Y2DIF,Z1DIF,Z2DIF,OFSET1,OFSET2
C
      DVALUE=25493.188
```

```
      X1GIVN=-740577.548
      Y1GIVN=-5456773.662
      Z1GIVN=3207660.081
      X2GIVN=-740336.501
      Y2GIVN=-5469717.020
      Z2GIVN=3185698.432
C
      READ(1,10,END=500) TTAG1,X1,Y1,Z1
      READ(1,11) SIGX1,SIGY1,SIGZ1
      READ(2,10,END=500) TTAG2,X2,Y2,Z2
      READ(2,11) SIGX2,SIGY2,SIGZ2
C
      IF(TTAG1.LT.TTAG2) GO TO 3
C
  2   CONTINUE
      READ(2,10) TTAG2,X2,Y2,Z2
      READ(2,11) SIGX2,SIGY2,SIGZ2
      IF(TTAG2.GE.TTAG1) GO TO 30
      GO TO 2
C
  3   CONTINUE
      READ(1,10) TTAG1,X1,Y1,Z1
      READ(1,11) SIGX1,SIGY1,SIGZ1
      IF(TTAG1.GE.TTAG2) GO TO 30
      GO TO 3
C
  30  CONTINUE
      IF(TTAG1.GT.TTAG2) GO TO 2
      IF(TTAG2.GT.TTAG1) GO TO 3
      DELX=X1-X2
      DELY=Y1-Y2
      DELZ=Z1-Z2
      DIST=DSQRT(DELX**2+DELY**2+DELZ**2)
      DELDST=DIST-DVALUE
C
```

```
      X1DIF=X1-X1GIVN
      Y1DIF=Y1-Y1GIVN
      Z1DIF=Z1-Z1GIVN
      X2DIF=X2-X2GIVN
      Y2DIF=Y2-Y2GIVN
      Z2DIF=Z2-Z2GIVN
      OFSET1=DSQRT(X1DIF**2+Y1DIF**2+Z1DIF**2)
      OFSET2=DSQRT(X2DIF**2+Y2DIF**2+Z2DIF**2)
C
      WRITE(4,42) TTAG1,TTAG2
      WRITE(4,43) X1DIF,Y1DIF,Z1DIF
      WRITE(4,41) OFSET1
      WRITE(4,43) X2DIF,Y2DIF,Z2DIF
      WRITE(4,41) OFSET2
      WRITE(4,41) DELDST
C
      READ(1,10,END=500) TTAG1,X1,Y1,Z1
      READ(1,11) SIGX1,SIGY1,SIGZ1
      READ(2,10,END=500) TTAG2,X2,Y2,Z2
      READ(2,11) SIGX2,SIGY2,SIGZ2
      GO TO 30
C
C  READ FORMATS
C
   10 FORMAT(D22.15,D22.15,D17.10,D17.10)
   11 FORMAT(31X,D17.10,4X,E10.3,4X,E10.3)
C
C  WRITE FORMATS
C
   41 FORMAT(D22.15)
   42 FORMAT(2D22.15)
   43 FORMAT(3D22.15)
C
  500 CONTINUE
      STOP
```

```
      END
C
//GO.FT01F001 DD DSN=MSS.S1643.MYTAPE,
//     DISP=(OLD,KEEP),MSVGP=PUB4B
//GO.FT02F001 DD DSN=MSS.S1643.FILENAME,
//     DISP=(OLD,KEEP),MSVGP=PUB4B
/*GO.FT04F001 DD DSN=MSS.S1643.CHECK,UNIT=3350,
/*     DISP=(NEW,KEEP),VOL=SER=MVS004,SPACE=(CYL,(4,4)),
/*     DCB=(RECFM=FB,LRECL=80,BLKSIZE=6400)
/*
//GO.FT04F001 DD DSN=MSS.S1643.filename,UNIT=3330V,
//     DISP=(NEW,CATLG,DELETE),MSVGP=PUB4B,
//     DCB=(RECFM=FB,LRECL=80,BLKSIZE=6400)
/*
//
```

APPENDIX C

LIST OF ABBREVIATIONS

AODC	Age of Data (Clock)
AODE	Age of Data (Ephemeris)
ARL:UT	Applied Research Laboratories: Univ. of Texas
ASCII	American Standard Code for Info. Interchange
CDU	Control and Display Unit
DMA	Defense Mapping Agency
DMAHTC	Defense Mapping Agency Hydro./Topo. Center
GEOSTAR	Geodetic Satellite Tracking and Ranging
GMT	Greenwich Mean Time
GPS	Global Positioning System
Mbps	Million bits per second
MCS	GPS Master Control Station
NAD-27	North American Datum of 1927
NAVSTAR	Navigation Satellite Tracking and Ranging
NSWC	Naval Surface Weapons Center
NSWC/DL	Naval Surface Weapons Center/Dahlgren Labs.
PPS	Precise Positioning Service
PRN	Pseudo-Random Noise
SPS	Standard Positioning Service
WGS-72	World Geodetic System of 1972

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11.	Ms. Ruth Darnell Naval Surface Weapons Center Code K-13 Dahlgren, VA 22448	1

12. Ms. Barbara Denoyer 1
Defense Mapping Agency
Hydrographic/Topographic Center
Code GST
6500 Brookes Lane
Washington, D.C. 20315

13. Mr. Carrol Griffin 1
Applied Research Laboratories
University of Texas at Austin
Austin, TX 78712-8029

14. Mr. Bruce Hermann 1
Naval Surface Weapons Center
Code K-13
Dahlgren, VA 22448

15. Director 1
Defense Mapping Agency
Hydrographic/Topographic Center
6500 Brookes Lane
Washington, D.C. 20315

16. Director 1
Defense Mapping Agency
Hydrographic/Topographic Center
Code HYT
6500 Brookes Lane
Washington, D.C. 20315

17. Director 1
Defense Mapping Agency
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Code GST
6500 Brookes Lane
Washington, D.C. 20315

18. Director 1
Defense Mapping Agency
Hydrographic/Topographic Center
Code HY
6500 Brookes Lane
Washington, D.C. 20315

19. Commanding Officer 1
Naval Oceanographic Office
NSTL Station
Bay St. Louis, MI 39529

20. Lt. Bruce Hillard, NOAA 1
NOAA Ship DAVIDSON
1801 Fairview Avenue, East
Seattle, WA 98102

21. Lt. Nicholas Perugini, NOAA 1
NOAA Ship RAINIER
1801 Fairview Avenue, East
Seattle, WA 98102

22. Mr. Peter Rakowsky 5
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Laurel, MD 20810

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